MODELING OF TOMB DECAY AT ST. LOUIS CEMETERY NO. 1:

THE ROLE OF MATERIAL PROPERTIES AND THE ENVIRONMENT

Judith Alleyne Peters

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Supervisor
Frank G. Matero
Associate Professor of Architecture

Reader
John A. Fidler
Head of Building Conservation
& Research
English Heritage

Graduate Group Chair
Frank G. Matero
Associate Professor of Architecture

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1.0 INTRODUCTION

Since 2000, the University of Pennsylvania, through the Graduate School of Fine Arts Departments of Historic Preservation and Landscape Architecture, has been developing conservation guidelines and a management plan for St. Louis Cemetery No. 1 in New Orleans, Louisiana. In March, 2001, a comprehensive site survey ((hereafter called *Survey*) of the landscape features and individual tombs was completed. This thesis combined the total site *Survey* information on tomb conditions with a literature review of decay mechanisms and environmental impacts and a laboratory material characterization of brick, stucco and mortar from specific tombs. Utilizing this information, deterioration scenarios were developed to explain current conditions. The sketches of these scenarios should be useful in educational materials and guidelines for conservation of aboveground cemeteries.

Owned and managed by the Catholic Archdiocese of New Orleans, St. Louis Cemetery No. 1, built in 1789, is the oldest surviving urban cemetery in New Orleans, Louisiana, and is of national, as well as local, significance. Among the many reasons for its importance are the cemetery's unique and early design, its reflection of New Orleans

social diversity, and the high quality and integrity of its architecture. It is one of only a few cemeteries on the National Register, and has also been identified as one of the country's *Save America's Treasures* sites.

The cemetery contains approximately 700 tombs and tomb ruins in small urban-like precincts. The tombs are owned by individuals, families and societies and most are aboveground and designed for multiple burials. Although there are a variety of tomb types and styles, a majority of the inventory consists of primary structures of soft, handmade, local "river" or "lake" brick and high lime content mortar, covered with high lime, hydraulic lime or natural cement content stucco. Until the mid-nineteenth century, the cemetery continued to develop. Tombs were added, smaller tombs were expanded with new additions, and most structures were kept in good repair. The yearly tradition of visitations and festivities on All Saints' Day provided an additional social reminder for family members to maintain the tombs. During this time, it is believed that the outer stucco covering on the tombs was kept intact and whitewashed, thus providing protection for the soft brick structure beneath.

By the late nineteenth century, St. Louis Cemetery No. 1 was showing advanced signs of decay and neglect, as many families had begun interring deceased members in newer cemeteries, and many of the older families had died out or left New Orleans. Periodic maintenance campaigns were spurred by concerned preservation groups or by the

Archdiocese. From field observations, it appears that the repair/restoration campaigns that occurred in the early to mid twentieth century involved liberal applications of high cement content stucco over the historic materials. Evidence also exists that many of the tombs were coated in modern finishes. These repairs have not held up well, and during the last decades of the twentieth century, restorations have begun to move in a disturbing direction. Many of the tombs placed in the "Perpetual Care" program, by families uninterested in or unable to provide long-term maintenance, have been fully or partially dismantled, the historic fabric discarded, and the structure rebuilt in reinforced concrete.

In this research, *Survey* condition data of the total site were analyzed and used to identify candidates for further material analysis. Geographical Information System (GIS) software was used to map conditions on both a site-wide and tomb specific level to study trends and patterns. A large sample set of individual materials and tomb systems was visually classified and generally evaluated for moisture absorption by total immersion. A selected subset of material samples and total systems was then tested further for moisture response by capillary absorption, drying rates, percent porosity, moisture vapor transmission, salt presence and composition. Normal and polarized light microscopy was used to analyze micro-structure, aggregate sorting, and composition. Specific stucco binder components were analyzed with Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) and Thermal Gravimetric Analysis (TGA).

A review of the available literature on material properties and decay processes, as well as testing methodology, was instructive in the adaptation of test methods to characterize such a large base of samples. The objectives in this research focused on property averages and comparisons to determine overall patterns of performance characteristics and decay mechanisms. The conclusions drawn and the illustrations of the decay processes provide guidance for basic conservation recommendations for tombs in St. Louis Cemetery No. 1. For individual restoration projects, further archival research and material analysis specific to each tomb, with an analysis of the specific issues of that tomb, would be advisable.

This characterization of tombs and analysis of building materials has confirmed the hypothesis that incompatibilities in building materials lead to certain moisture driven decay patterns. When subjected to the high heat and humidity of New Orleans, the differing hygroscopic properties of the materials in the system have exacerbated and accelerated decay mechanisms, resulting in gross cracking and delamination, with resultant stucco, mortar and brick loss. Without the periodic maintenance routines that were in place historically, these deterioration results grew into major structural failures. The overall condition of the site today is primarily the result of years of neglect and deferred maintenance and many of the repairs that were made have tended to exacerbate masonry deterioration caused by the differing properties of the original and repair materials.

2.0 ST. LOUIS CEMETERY NO. 1 – HISTORICAL CONTEXT

2.1 New Orleans – A City Develops in Spite of the River

By the mid-seventeenth century, the French had established themselves in North America by claiming and settling around the St. Lawrence River and the Great Lakes, in the region now known as Quebec. They recognized the strategic importance that control of the waterways provided and sought to secure the mouth of the great Mississippi River. On April 9, 1682, the land now known as Louisiana was claimed for France by Robert Cavalier de La Salle and was named Louisiane, for Louis XIV. By 1700, there were French soldiers in the region to protect the area from encroachment by the Spanish, who already had colonies in Florida and had laid claim to the gulf coast of the North American continent. In 1717, John Law, a Scot, was given the exclusive charter to sell real estate and develop Louisiana for the French. Settlers from France and Germany were lured to New Orleans expecting financial opportunities and a healthy climate. Instead, most found an early demise in the mosquito and snake infested bayous.

Most historical commentators remarked on the poor, yet perfect location of the city founded in 1718 as New Orleans by Jean Baptiste Lemoyne de Bienville, the then Governor-General of Louisiana. Its history and development have been inextricably

linked to the Mississippi River, with its large delta of below sea level swamp and marshland. The city is sited on a great bend in the Mississippi River bounded to the north, west and south by the river and the east by a large lake, Lake Pontchartrain. It lies near the mouth of the river, and near enough to bayous that could be navigated, so that a sheltered, deep-water port could be established.[1] The strip of land almost a mile wide along the river's bend was the best and closest area that Bienville encountered while exploring northward from the mouth of the river It was on relatively high ground and was considered large enough for a development. Economically and geographically, this original crescent of land was the perfect site for shipping and control of the waterways, and the best of many bad sites for building a new city. In spite of the lack of local building stone and other resources, and the almost yearly yellow fever epidemics and other plagues, "New Orleans grew rapidly and before the Civil War, was the wealthiest and third largest city in the United States."[2]

Fig. 2.1
Map of the Louisiana Coast, 1719-20, by M. de Serigny. THNOC 22.1

[1] Donnald McNabb and Lee Madere, *A History of New Orleans* (New Orleans: Lee Madere, 1997), 3.
[2] Stein, Joseph A. "New Orleans," *Pencil Points* v. 19 (1938 April): 197.

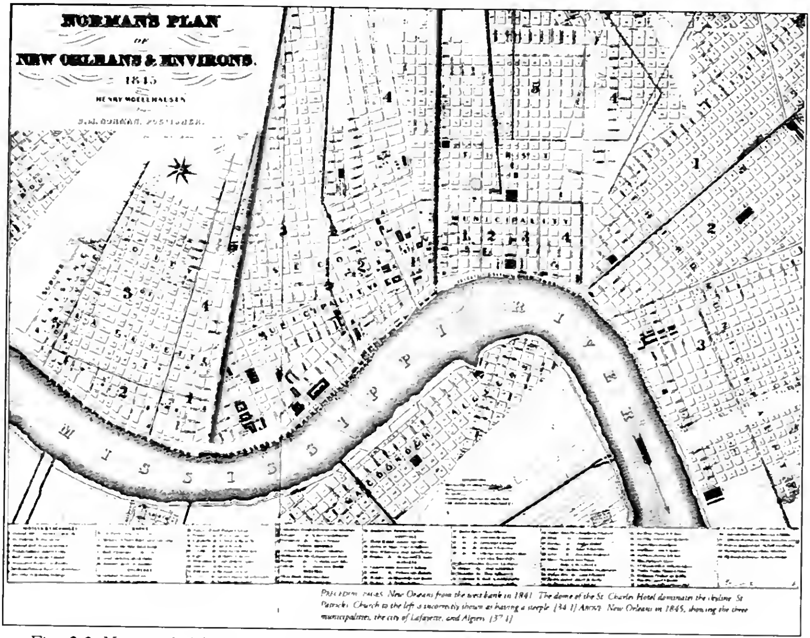

Fig. 2.2 Norman's Plan of New Orleans Environs, 1845, Special Collections, Tulane Univeristy.

The history of New Orleans under the French, the Spanish, the French again, and finally, as part of the Louisiana Purchase, becoming a part of the United States of America, is rich and fascinating, and far beyond the scope of this thesis.[3] The environment and the city's constant battle with water, the mix of French, Spanish and American cultures, the Creole society, the large influxes of immigrants, the almost yearly yellow fever or plague epidemics, the city's pattern of growth, the unique development of laws, and, of course the architecture, have all impacted the

[3] The New Orleans History section of the Bibliography contains many excellent sources for the study of the history and architecture of New Orleans and the aboveground cemeteries.

development of the cemeteries. New Orleans history, geography and culture have also influenced building materials of choice and attitudes towards cemetery maintenance and preservation, and will be important elements to understand in the development of plans to arrest the current levels of decay and initiate long-term plans for maintenance and protection of this important cultural landscape.

2.2 St. Louis Cemetery No. 1 - Development and Change

For the early years of settlement, it has been assumed by many authors that burials occurred in the high ground of the riverbank, although this fact has never been verified archaeologically or through archival records. During high rainy seasons, this land flooded and remains would have been disturbed. In a 1721 plan for the city, Royal Military Engineer Adrian DePauger included an area for a cemetery outside of the city limits, where St. Peter Street is today. This low, swampy site was surrounded by ditches in an attempt to drain excess water, and burials were made below ground. Prominent citizens were not buried in the watery graves in St. Peter Cemetery, as they could command space within the parish church of St. Louis, as was the custom in Europe. The burial space in the Church quickly neared its maximum capacity, and in

1784, the Spanish Cabildo, fearing disease from over burial, prohibited interment in the church of all but the most distinguished inhabitants of the colony.[4]

In 1788, New Orleans lost many citizens to an epidemic and a great fire. The St. Peter Cemetery was over-filled and there was a growing belief that interring the dead among the living contributed to outbreaks of disease. The Cabildo ordered a new cemetery to be established outside the city limits. St. Louis Cemetery, now called St. Louis Cemetery No. 1, was established to the north of the city, outside the ramparts in the area now bound by Basin, Conti, Tremé and St. Louis streets. The 300 foot square space was considered temporary until officially approved on August 14, 1789, when a royal decree was issued in which "His Majesty was pleased to approve the construction of the new cemetery."[5]

After disastrous fires in both 1788 and 1794, the Spanish Cabildo passed building laws that forbade the construction of wooden buildings within the center of the city, "requiring walls to be of brick or of brick between posts protected by at least an inch of cement plaster."[6] New Orleans became a city of brick buildings and these building practices also became the norm for tomb and cemetery wall construction. "After 1803 the rapid increase in population, together with the inroads made by yellow fever and

[4] Mary Louise Christovich, ed., *New Orleans Architecture, Vol. III—The Cemeteries* (Gretna: Pelican Publishing, 1974), 4.
[5] Records and Deliberations of the Cabildo, Oct. 17 1788, typescript, WPA, 1936.
[6] Samuel Wilson, Jr., "The Architecture of New Orleans," *AIA Journal* (August 1959): 32-35.

cholera, created a real municipal problem. ...Rigid regulations regarding methods of burial were issued. Interment in the ground was forbidden, and brick tombs were required in all cemeteries which were enclosed within high brick walls."[7] It was at this time that burials within the church were also abolished.[8]

Although interments continued at St. Peter Cemetery until it was closed in 1800, St. Louis Cemetery No. 1 was the primary location for all burials in the city until the consecration of St. Louis Cemetery No. 2 in 1823.[9] The growth of the city and the high death toll from yellow fever made more burial space necessary. There are still many tombs in St. Louis Cemetery No. 1 that have dates after 1823, such as the one seen in Figure 2.3, as family plots were built, added onto or tombs rebuilt throughout the nineteenth century. New building activity slowed dramatically by the late nineteenth century, as there were a number of more fashionable cemeteries throughout the city, and many of the tombs at St. Louis Cemetery No. 1 fell into ruin.

Fig. 2.3 Closure Tablet Tomb #251, 1st visible date is 1826.

[7] Federal Writers' Project of the Works Progress Administration for the City of New Orleans, *New Orleans City Guide* (Boston: Houghton Mifflin, 1938), 186.
[8] Records and Deliberations of the Cabildo, December 28, 1803, typescript WPA, 1936.
[9] Christovich, 6.

2.3 Tomb Types and Traditional Construction

St. Louis Cemetery No. 1 is described as an aboveground cemetery, although there exist below ground burials there, as there were at St. Peter Cemetery. According to Louisiana historian Eric J. Brock,

> the tradition of above ground interments is more cultural than practical (though certainly the practicality of the method in New Orleans' particular environment played a role in its adoption.) Above ground interment is common throughout the Latin world and, indeed, is more the rule there than the exception.[10]

Fig. 2.4 Aboveground tombs.

Sharyn Thomson described low individual tombs of brick, common in late eighteenth, early nineteenth century cemeteries throughout the coastal American south and the West Indies, that appear similar to the low step and platform tombs at St. Louis Cemetery No. 1.[11]

By studying archival records with recent survey results and data on the first evident interment date, one can see a progression in the construction of tomb types and in their

[10] Eric J. Brock, *Images of America: New Orleans Cemeteries* (Charleston: Arcadia Press, 1999), 7.
[11] Sharyn Thompson, "These Works of Mortuary Art: The Aboveground Tombs of St. Michael Cemetery, Pensacola, Florida," *Southern Quarterly* 31 (2) (Winter 1993): 50-73.

later renovations and additions. The March, 2001, *Survey* of St. Louis Cemetery No. 1 by The University of Pennsylvania, Graduate School of Fine Arts Collaborative Studio, identified the major tomb types.[12]

Wall Vault: Multiple tiers of individual burial vaults, usually of brick vault construction, arranged to form an isolated block, usually serving as a perimeter enclosure wall.

Pediment Tomb: A multiple vault tomb with a height greater than either its width or length and surmounted by a pediment. (Pediment: the flat, triangular or curved gable end of the roof surmounting the end walls.) These are usually family tombs.

Simple Tomb: This tomb type has multiple variations that will be referred to as the sub-types. A simple tomb is a small mortuary structure, that contains one or more burial vaults within solid walls and whose length is greater than its width or height. There are several classifications of simple tombs:

- **Platform tomb:** A simple tomb whose base is solid or open on piers or columns.
- **Parapet tomb:** A simple tomb possessing a raised front creating a parapet (a low wall surmounting the structure's exterior walls or at a roof's perimeter), with or without embellishment.
- **Sarcophagus tomb:** A simple tomb resembling a sarcophagus, typically with canted sides and usually on a raised base.
- **Step tomb:** A simple tomb possessing a stepped or corbelled top.

When New Yorker John Pintard visited the cemetery in 1801, he described a landscape very different from the image of St. Louis Cemetery No. 1 today. The graves were not marked and the tall pediment aboveground tombs common today were not remarked as

[12] The Collaborative Studio was developed in 2000 in conjunction with Save our Cemeteries, Inc., and the Roman Catholic Church of the Archdiocese of New Orleans by the University of Pennsylvania's Graduate School of Fine Arts Departments of Historic Preservation and Landscape Architecture with Tulane University's School of Architecture/Preservation Studies. Funding was made available by the Louisiana Division of Historic Preservation, Office of Cultural Development and Tourism. They also provided further funding Phase 2 archival research, map and database work, and for the development of Preservation Guidelines.

dominant. There still remain several good examples in St. Louis Cemetery No. 1 of the low step tombs that Pintard described, such as the two seen in Figure 2.5. He commented:

> Over some few, brick arches were turned. At the head of every grave was planted an Iron or wooden cross some of the Iron ones were indented with the names of the lifeless tenants below.[13]

Fig. 2.5. Early Step Tombs.

Cemeteries have developed around two models. The rural cemetery, or Elysian Field, is viewed as a garden of graves. In fact, one definition of "cemetery" is "place of sleep." The Necropolis, or city of the dead model as that found at St. Louis Cemetery No. 1, is predominantly architectural. This is not the model most Americans found familiar or comfortable. As Senator Hoar expressed when first viewing the heavy monuments Benjamin Latrobe designed for the Congressional Cemetery, "the thought of being buried beneath one ... added new terror to death."[14]

Most of the travel journals that reference New Orleans were written by visitors from the Northeast, where church graveyards were the norm and where the rural cemeteries first

[13] David Lee Sterling, "New Orleans, 1801: An Account by John Pintard," *Louisiana Historical Quarterly* Vol 34 no 3 (July 1951): 230. John Pintard wrote a series of articles published in the *Daily Advertiser* from April 15 to May 22, 1802, while an editor of that paper in New York City. The original manuscript is held by the New York Historical Society.

[14] Edward F. Bergman, *Woodlawn Remembers: Cemetery of American History* (Utica, NY: North Country Books, 1988), 2.

developed in the 1830s. They were most comfortable with the rural cemetery, or Elysian Field model, a garden of monuments. When confronted with the Necropolis, or city of the dead model, they commented with fascination, puzzlement and sometime, revulsion.

In 1818, Benjamin Latrobe described a cemetery that contained stucco covered brick platform, and possibly pediment tombs, as well as wall vaults. He sketched 4 platform tombs in his journal, and a wall vault in two sections, one with 7 bays and one with 9 bays, each 3 tiers high.

> The Catholic tombs are of a very different Character from those of our Eastern and Northern cities. They are of bricks, much larger than necessary to enclose a single coffin, and plaistered [sic] over, so as to have a very solid and permanent appearance. They are of these and many other Shapes of similar character covering each an area of 7 or 8 feet long and 4 or 5 feet wide, and being from 5 to 7 feet high.[15]

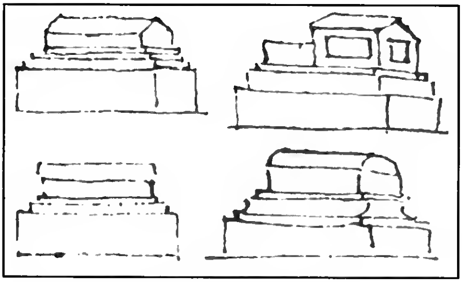

Fig. 2.6 Benjamin Latrobe's sketches of the aboveground platform tombs. He also made 2 sketches of the wall vaults. From the Benjamin Latrobe Journals.

> In one corner of the Catholic burying grounds are two sets of Catacombs of three stories each . . . Many of the Catacombs were occupied, but not in regular succession and the mouths of some were filled with Marble Slabs having inscriptions. But more were

[15] Benjamin Latrobe, March 8th 1819. This quote can be found in publications of the Latrobe's Journals. From Samuel Wilson, Jr. ed., *Impressions Respecting New Orleans by Benjamin Henry Boneval Latrobe: Diary & Sketches 1818-1820*, (New York: Columbia University Press, 1951), 82;and Edward C. Carter II, John C. Van Horne, and Lee W. Formwalt, eds. Samuel Wilson, Jr. Consulting Ed. *The Journals of Benjamin Henry Latrobe 1799-1820 From Philadelphia to New Orleans*, (New Haven: Yale University Press for The Maryland Historical Society, 1980), 241.

> bricked up and plaistered [sic] without any indication of the person's name who occupied it.[16]

Timothy Flint, a protestant missionary from New England, spent 10 years traveling throughout the Mississippi valley. He was conflicted concerning his assessment of the "morals" of the people of New Orleans, as he found so many contrasting practices of what he felt was good and evil, but found the cemetery impressive. In 1822 he wrote:

> The old Catholic cemetery is completely covered either with graves or monuments. The monuments are uniformly either of white marble, or plaister, or painted white, and by the brilliant moonlight evenings of this mild climate, this city of the dead, or as the more appropriate phrase of the Jews is, of the living, makes an impressive appearance.[17]

Benjamin Latrobe's youngest son, John H. B. Latrobe painted a more colorful view that gives us the first clear image of St. Louis Cemetery No. 1 in 1834. The pyramidal Varney tomb is prominent, and there are step and platform tombs illustrated in earth colored stuccos. Multiple burial tombs, open space, wall vaults, and ships in the canal beyond are documented:

> We went to the Catholic burying ground. The tombs here are peculiar to the place. No grave could be dug of the usual depth without coming to water, and to obviate this difficulty in the sepulcher of the dead, the coffin is laid upon the surface of the ground, and a strong structure of brick built around it. This is then plastered and whitewashed.[18]

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[16] Ibid, Wilson, 83, Carter, 242.

[17] Timothy Flint, *Recollections of the last ten years, passed in occasional residences and journeyings in the valley of the Mississippi*, (1826 reprint, New York: Johnson Reprint Corp., 1968), 225.

[18] Samuel Wilson, Jr. and Leonard V. Huber, *The St. Louis Cemeteries of New Orleans* (New Orleans: St. Louis Cathedral, 1963), 5, quoted from John E. Semmes, *John H. B. Latrobe and His Times – 1803-1891* (Baltimore, 1917).

Fig. 2.7 St. Louis Cemetery No. 1 in 1834, Watercolor sketch by John H.B. Latrobe. Image reproduced from cover art on The St. Louis Cemeteries of New Orleans, *October, 1998, published by St. Louis Cathedral. The original artwork was owned Mrs. Ferdinand Claiborne Latrobe, II, of Baltimore.*

Cyril Thornton, writing in 1834 in *Men and Manners* found the whole idea of a watery grave very repugnant during his visit to the cemetery. The lurking pools of water and visible crayfish must have made more of an impression on him than did the aboveground tombs, as his comments reflect:

> One acquires from habit a sort of lurking prejudice in favour of being buried in dry ground, which is called into full action by a sight of this New Orleans cemetery. The space cannot penetrate even a few inches below the surface, without finding water, and considerable difficulty is experienced in sinking the coffins, since the whole neighbourhood could not furnish a stone the size of an orange.[19]

[19] Cyril Thornton, *Men and Manners in America*, 2nd ed. vol. II (Edinburgh: William Blackwood, 1834), 215.

By the travel accounts of Ingraham (1835), Didimus (1845), and Lady Emmeline Stuart Wortley (1848-50) and Fredrika Bremer (1855), the beauty of the aboveground tombs of St. Louis Cemetery No. 1 and 2 were better appreciated and the concern of inground watery graves ceased to be mentioned.[20] It is during this time that the well-read traveler became aware of cemetery advances in Paris at Père Lachaise, established in 1804, and the rural cemeteries such as Mt. Auburn (1831) in Massachusetts or Greenwood (1835) in Brooklyn, NY. It is also by the mid 1830s that the marble clad tombs designed by French émigré Jacques Nicolas Bussiere dePouilly were commissioned by prominent families for tombs in St. Louis Cemeteries No. 1 and 2 turning St. Louis Cemetery No. 1 and especially No. 2 into a more monumental park.[21]

In 1875, Mark Twain summed up the unique situation of New Orleans' architectural necropolis:

> There is no architecture in New Orleans, except in the cemeteries" and went on to describe the cemetery and the well-maintained nature of the individual tombs. ...They bury their dead in vaults above ground. These vaults have a resemblance to houses - - sometimes to temples; are built of marble, generally; are architecturally graceful and shapely; they face the walks and driveways of the cemetery; and when one moves through the midst of a thousand or so of them, and sees their white roofs and gables stretching into the distance on every hand, the phrase 'city of the dead' has all at once a meaning to him. Many of the cemeteries are

[20] Joseph Holt Ingraham, *The South - West By a Yankee,* vol. 1 (New York: Harper & Brothers, 1835), 145,154-55; H. Didimus, *New Orleans As I Found It* (New York: Harper & Brothers, 1845). Lady Emmeline Stuart Wortley, *Travels in the United States etc. During 1848 and 1850* (New York: Harper & Brothers, Publishers, 1851), 126; Fredrika Bremer, *The Homes of the New World; Impressions of America*, trans. Mary Howett (New York: Harper and Brothers, 1854), 214.
[21] Masson, Ann M. "Père La Chaise and New Orleans Cemeteries." *The Southern Quarterly: A Journal of the Arts in the South* 31, no. 2 (Winter 1993) 82-97.

> beautiful and kept in perfect order ... if those people down there would live as neatly while they were alive as they do after they are dead, they would find many advantages to it.[22]

In the mid 1870s, George François Mugnier photographed St. Louis Cemetery No. 1, leaving us many images of the cemetery tombscapes while it was still an active cemetery. The Society tombs that now dominate the view of the western section of St. Louis Cemetery No. 1 had already been built. Most family tombs seen in the Mugnier views are pediment tombs or large platform and parapet tombs with multiple vaults. By this time, many of the early single vault platform tombs had been "made-over" to accommodate multiple vault family burials. These "addition" tombs can be identified by changes in brick coursing or stucco, or tell-tale construction lines and odd placement of original tablets.

By the late 1870s, the images of St. Louis Cemetery No. 1 were defined by the large society tombs, such as those sketched by A. R. Waud, and published in 1867 by *Harpers Weekly* and by the photography of Mugnier. In 1879, a reporter for *Times Picayune* wrote about All Saints' Day, during which families and society members repaired, cleaned, whitewashed and decorated the tombs.

> The cemetery on Basin and St. Louis Streets [No. 1] witnessed a large concourse of people . . . Here the tomb of the Lusitanos Portuguese Benevolent Association is situated. It was draped in mourning and surmounted by various Portuguese flags. The Italian Benevolent Society's fine tomb was decorated with flags and draped in black. The

[22] Louis M. Hacker, ed. *Mark Twain, Life on the Mississippi*. (New York: Sagamore Press, Inc., 1957), 223.

> Societé Française, Orleans Artillery, Catalan Society, Sieurs Bien Aimée and other societies bedecked their tombs in becoming manner.[23]

2.4 The Evolution of Restoration Practices

By the end of the nineteenth century, St. Louis Cemetery No. 1 had fallen out of favor as New Orleans residents moved out to the more fashionable cemeteries of Lafayette and Metairie. As interment activity fell, so did visitation and family maintenance activities. Grace King, the noted New Orleans historian, wrote in 1895 of a cemetery that was no longer open to visitors:

> The crumbling bricks of the first resting–places built there are still to be seen, draped over with a wild growth of vine, which on sunshiny days are alive with scampering, flashing, green and gold lizards. It opens its gates only at the knock of an heir, so to speak; gives harbourage only to those who can claim a resting place by the side of an ancestor.[24]

Lafcadio Hearn was less flattering when he wrote of his city's earliest cemeteries. His harsh words were not for the manner of burial, but for what the lack of care and maintenance had caused in the cemetery:

> They are hideous Golgothas, these old intramural cemeteries of ours. ... The tombs are fissured, or have caved in, or have crumbled down into shapeless masses of bricks and mortar; the plaster falling away, betrays the hollow mockery of the frail monuments.[25]

[23] *New Orleans Times Picayune*, November 1, 1879.

[24] Grace King, *New Orleans: The Place and The People* (New York: Macmillan and Co., 1895), 401.

[25] Lafcadio Hearn *Creole Sketches*, Charles Woodward Hutson, ed. (Houghton Mifflin Company: Boston and New York, 1924), 137. This publication reprinted work by Hearn written in 1885.

In the 1885 Historical Sketch Book and Guide to New Orleans and Environs, the authors described St. Louis 1 Cemetery and its condition:

> … the older cemeteries, such as the St. Louis, … were once the outskirts of the town, are now in the heart of the populous parts of the city, and every consideration of public sanitation demands that they be closed against further interments. … In this cemetery many of the oldest tombs are so dilapidated that they cannot be identified and some are missing altogether.[26]

In 1900, it was stated in the *Standard History of New Orleans*: "Many of the tombs are empty and falling to pieces, the tablets gone, or so worn by winter's storms and summer's heats that the inscriptions are no longer legible."[27]

In 1923, in response to these conditions, Grace King and other concerned citizens formed the Society for the Preservation of Ancient Tombs. The 150 members, undertook a research project to determine the location and condition of tombs of greatest historical significance, and started efforts to have them restored.[28] During the WPA (Works Progress Administration) projects of the 1930s, the documentation research was extended and inscriptions for most of the tombs were documented for each New Orleans cemetery. The card files of this research are now archived at the New Orleans Public Library.

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[26] *Historical Sketch Book and Guide to New Orleans and Environs, With Map* (New York: Will H. Coleman, 1885), 223, 225.
[27] A.G. Durno. "Old Burial Places," *Standard History of New Orleans*, Henry Rightor ed. (Chicago: Lewis Publishing Co, 1900), 257.
[28] Christovich, introduction by Samuel Wilson, Jr., ix.

It is clear that the interest generated by the Society for the Preservation of Ancient Tombs and the new information provided by the WPA project created momentum for tomb repair and maintenance. There are many early tombs in St. Louis Cemetery No. 1 with original brick walls and cornice details, now patched or completely recoated in modern cement stucco. Many of these repairs may have occurred during the enthusiasm generated by the work of King's group and the new cemetery information published by the WPA, in a time before the development of professional conservation practices.

In 1948, Joseph S. Carey wrote the *Saint Louis Cemetery Number One Souvenir Booklet* which contains photographs of the cemetery and a self-guided walking tour of famous tombs and residents.[29] By this time, the cemetery's condition had been improved enough to invite the public back in for visits. In the later publications of *The St. Louis Cemeteries of New Orleans* by Samuel Wilson, Jr. and Leonard V. Huber in 1963, 1988 and 2001, this original list of highlighted tombs is repeated with very little new research added.[30] During the 1970s and early 1980s, several large restoration projects were completed by the Archdiocese and bronze plaques were added to many of the tombs highlighted in Carey's booklet.

[29] Joseph S. Carey. *Saint Louis Cemetery Number One, Souvenir Booklet* (New Orleans: St. Louis Cathedral, 1948).
[30] Samuel Wilson, Jr. and Leonard V. Huber. *The St. Louis Cemeteries of New Orleans* (New Orleans: St. Louis Cathedral, 1963 and 1988).

In 1974, Mary Louise Christovich, New Orleans author and historian, founded Save Our Cemeteries, Inc. (SOC) in an effort to increase awareness of the restoration needs of the city's cemeteries and to build support to stop the nine city-block demolition of the condemned wall vaults of St. Louis Cemetery No. 2 by the Archdiocese. That same year, the Friends of the Cabildo and LA State Museum published a cemeteries volume of the *New Orleans Architecture* Series (Vol. III), hoping to "focus attention and inspire positive action for the protection and preservation of what remains of this priceless historical and architectural heritage."[31]

Fig. 2.8 Tomb #475, A Perpetual Care tomb being rebuilt, replacing the original historic materials.

Since that time, sporadic conservation projects by families, the Archdiocese and cemetery preservation groups have been completed at St. Louis Cemetery No. 1. The Archdiocese has encouraged tomb owners to place their tombs under the Perpetual Care program which ensures that the tomb will be maintained long after the final interment. While this program could be beneficial toward the preservation of these historic tombs, the

[31] Christovich, introduction by Samuel Wilson, Jr. x of Forward.

actual results had quite the opposite effect. Tombs placed under Perpetual Care have been completely or partially dismantled and a new tomb or roof of reinforced concrete, painted bright white, has been erected in its place. Often, only the original marble tablet is preserved, to be inset into the side of the concrete tomb while a gray granite tablet is placed in the vault opening. These new tombs bear very little resemblance to the historic tombs that remain in the cemetery, and are quite visually jarring to the overall appearance of the cultural landscape that the cemetery has become.[32]

Fig. 2.9 Marble tablet repaired with an incompatible epoxy adhesive.

Also distracting are tomb restorations by families and tomb restoration groups, who are not well informed on appropriate conservation practices, such as advocated by the *Secretary of the Interior Standards for Historic Preservation*, or specific guidelines for cemetery preservation published by the State of Louisiana.[33]

[32] During the 1981 survey, there were 7 Perpetual Care tombs noted. By the 2001 survey, the number had grown to 57. There were 10 additional tombs without a Perpetual Care plaque that were marked with a special informational plaque as "Restored by the Archdiocese."

[33] Kay D. Weeks and Anne E. Grimmer, The Secretary of the Interior's Standards for the Treatment of Historic Properties with Guidelines for Preserving, Rehabilitating, Restoring & Reconstructing Historic Buildings, Washington, D.C.: National Park Service, 1995; Frank G. Matero, *Cemetery Preservation: The Restoration of Above Ground Masonry Tombs*, New Orleans, LA: Louisiana Division of Historic Preservation, Save Our Cemeteries, Inc., 1989.

In spite of these issues, the current situation at St. Louis Cemetery No. 1 is encouraging. Through funding and support by the Louisiana Division of Historic Preservation, Office of Cultural Development and Tourism, Save Our Cemeteries, Inc. and the Archdiocese of New Orleans, the results of the *Survey*, the restoration of three pilot tombs and the second phase of research on history, tomb construction and material properties have been completed and incorporated into new guidelines for the site. The Archdiocese, as owner and manager of the site, is actively involved with the preservation planning process. Tomb restoration funding has been made available with a grant from *Save America's Treasures* and a project team is working to stabilize emergency tomb conditions and complete a full tombscape conservation project on Alley 9-L, in the northwest corner of the site. It is hoped that the information and scenarios of decay developed in this research can provide meaningful assistance to tomb owners and people in cemetery management, as well as the many enthusiastic volunteers willing to provide donations and physical labor towards future tomb conservation and restoration.

Fig. 2.10 Bergamini Tomb #12,
One of the SOC pilot restoration tombs.
Photograph by Studio, March 2001.

3.0 TOMB DECAY MECHANISMS

3.1 Development of Hypotheses

This research was initiated to investigate how known decay mechanisms have impacted the tombs at St. Louis Cemetery No. 1, given how the structures were originally designed to function and endure. The tomb designs and original materials of construction, primarily local brick protected by lime and hydraulic stuccos, were selected empirically by generations of New Orleans craftspeople. Over time, alterations have been made to many of the tombs, and both structural and material changes have been considered in this research, although the hypotheses formed assumed that mismatches in material properties and the local hot, humid wet environment would be the most important factors.

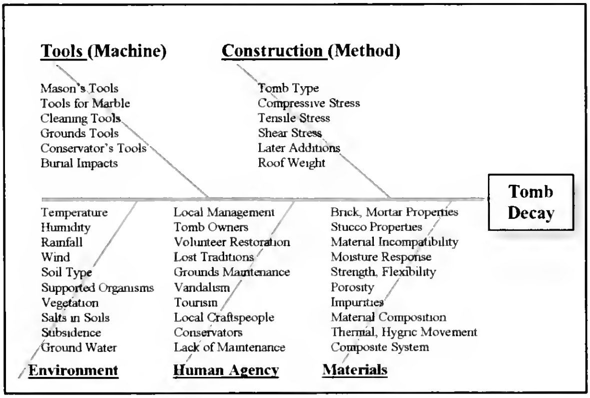


Fig. 3.1 Cause-and-effect diagram for tomb decay.

A cause-and-effect diagram, as a visually oriented problem solving tool, highlights the major

categories where problems occur in any situation where variation or deterioration is active.[34] The historical context and technical literature review uncovered many of the potential causes under the categories of people, tools and techniques. The laboratory analyses focused on materials and environment.

In the development of the hypotheses, tomb construction, the specific properties of the materials of construction, and environmental impacts were considered. This consisted of a review of tomb structure, form and function, historic information and performance property issues with each primary building material, as well as the specific New Orleans' environmental factors contributing to decay. With that information as background, decay mechanisms were evaluated for their potential as the primary drivers to surface and structural degradation at St. Louis Cemetery No. 1.

3.2 Tomb Construction – Form and Function

The major purposes of the structural systems of the building, and in this case, a tomb, are to protect the interior contents from exterior forces. A poorly designed structure will not last long enough to serve the multi-generational burial needs and the tombs at St. Louis Cemetery No. 1 have actually performed well over time in their function to

[34] These "Fishbone" cause-and-effect diagrams are often used to solve problems in manufacturing systems or service processes, but can also be useful when diagnosing conservation issues. They were popularized in the U.S. by Dr. Kaoru Ishikawa, a Japanese quality control expert. The five key areas in which all sources of variation can be found are man, machine (tools), method (technique, procedure), material and environment. These five categories are often renamed to better fit the specific process or problem.

protect the interred. Deterioration has occurred primarily due to the structure's lessening ability to minimize mechanical stresses, because of the gradual disintegration, or replacement, of what were once adequate and properly erected structural systems.[35] Once deformations began to occur, the crystalline nature of the building materials reacted to deformation stress by cracking on the microscopic and macroscopic levels.

The majority of the tombs in St. Louis Cemetery No. 1 are simple constructions of stucco covered brick. With the exception of the step tombs, most of the tombs are meant to contain one or more aboveground interments, each in an individual vault. According to a city ordinance, after at least one year and one day, a vault can be reopened, the casket burned or discarded and the decomposed remains can be transferred to the lowest *caveau* level, or pushed to the back of the vault, if the family requires space for another interment.[36]

For illustration purposes, each level or tier of vaults can be considered a floor and the *caveau*, if it exists, can be thought of as the basement. Tombs can be structurally described, as would an architectural building, by the number of floors (tiers) and bays over a basement (*caveau*) level and covered by a roof of a specific style. The openings in the tomb are created by the vault openings, which are sealed by loose brick and

[35] Samuel Y. Harris, *Building Pathology (*New York: John Wiley & Sons, 2001), 58.
[36] Interview with Michael Boudreaux, Director, Archdiocesan Cemeteries of New Orleans on March 13, 2001.

mortar and covered by a closure tablet made historically of marble. The modern tablets are often of granite.

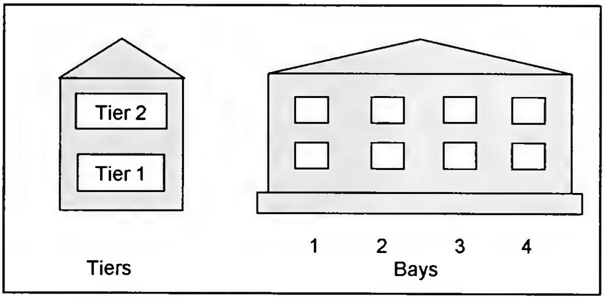


Fig. 3.2 Vault configurations for aboveground tombs. Sketches from the Survey Manual.

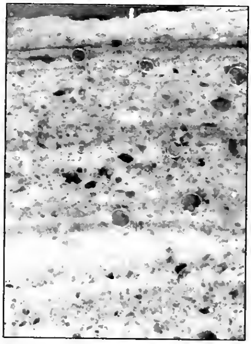
In the simplest low step tomb, the brickwork generally follows the form of the casket over which it was built, and these tombs were not meant to be reused.[37] However, for the majority of the multi-vault tombs in St. Louis Cemetery No. 1, the structural system consisted of load bearing brick masonry walls, generally at least 2 wythes wide, with stepped brickwork or arches forming each vault. The brickwork was laid in various bonds, but generally the exterior wythe was an American bond with several (4-6) courses of stretchers before a header course was laid. In many of the tombs, a stone slab was placed over the vault to provide a supportive floor to the next vault or to the roof. Most of the tombs in St. Louis Cemetery No. 1 did not have a separate stone foundation, although many had a thicker brick base composed of an extra wythe of brick for 2 or more courses. In tombs that have had later additions, the upper addition

[37] Of the 17 low step tombs surveyed, only 1 had a tablet listing more than one interment.

may be slightly smaller than the original tomb, with the original tomb creating an apparent wider base.

Fig. 3.3 Apparently, this pediment tomb was built over an earlier step or platform tomb. Note the different bricks used for each different period of construction.

Depending on the tomb style, non-structural brickwork was used to form a pediment or a high parapet over the vault openings to create an impressive tomb entrance. Intricate profile cornices were often formed around this brickwork with stucco. All local brickwork was protected by stucco and most tombs were originally limewashed in white or earth colors. Multiple layers of both stucco and surface finish can be seen on many of the tombs representing generations of choice in both color and materials.



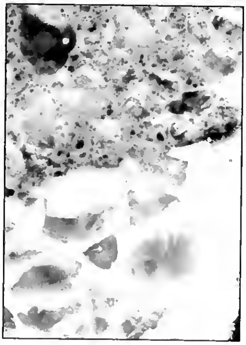


Fig. 3.4 Tomb # 267 Multiple layers of finish, 12.5 x magnification.

Fig. 3.5 Tomb # 600, Multiple stucco layers, Original "Tan" lime stucco on bottom, More recent "Gray" cementitious stucco on top. 12.5 x magnification.

The wall and roof closure systems, and all additional structural elements added to keep openings and cavities from compromising the purpose of the structure, worked together to minimize distortion and protect the interior contents. The walls, acting as the vertical closure system, provided barrier protection from corrosive and deteriorative elements, and served to carry the roof. The stucco layers of the wall protected and ensured the structural integrity of the brick super-structure, while the brick masonry provided protection for the interior space. As designed, in an unbroken layer, the stucco served its function well by keeping water, windblown seeds and biological growth away from the interior brick and mortar. However, when not maintained, cracks that developed in the stucco could channel water into the structure, where it would cause serious structural degradation.

The roof closure system served to collect and divert water away from the tomb, and provided structural stabilization to the tops of the walls. The components of this system included the roof and any additional site or design elements that affected the water drainage ability of the tomb. The most critical function of the tomb roof was to keep falling or wind-driven water out of the interior structural brickwork. If the roof system was breached by any small crack, water could enter and many of the decay processes would be initiated. Once the roof failed, deterioration of the tomb structure was rapid.

In an architectural structure, one would normally design openings and cavities for ventilation and human comfort. In the St. Louis Cemetery No. 1 tombs, there were no "live" inhabitants, and the openings were rarely unsealed. The openings are part of the arched or trabeated vault and the weight of the structure is completely supported by the brick walls and the arch or slab. The opening was sealed with odd bricks and mortar, and usually stuccoed over and then faced with a closure tablet of marble or other stone. The opening did not compromise the structure, and while sealed, the closure tablet system over the mortared opening was effective in protecting the interior of the tomb from water intrusion. Even where tablets were loose or cracked, the vertical nature of the tablet was still effective as a closure system. Based on numerous visits to this site, it was apparent that the social and cultural taboos of an open tomb are such that these openings were not allowed to stay unsealed long because of decay and deterioration, even though the rest of the tomb structure may be completely compromised. Tombs that become opened through vandalism are closed by the Archdiocesan Cemeteries' staff.

3.3 Construction Materials

3.3.1 The Integrated Assembly System

The tombs at St. Louis Cemetery No. 1 are composite systems made up of disparate construction materials, each with its own distinct properties. According to Binda and

Anzani, "Modeling a masonry structure is a difficult task, since masonry does not apparently respect any hypothesis assumed for other materials (isotropy, elastic behavior, homogeneity). … masonry must be viewed as a composite. Its mechanical properties are derived from the properties of the components"[38] To begin to understand the system, the individual material properties were studied, then interactions at the interfaces were considered based on the individual decay mechanisms.

3.3.2 Brick

The American Society for Testing Materials and Materials defines brick as "a solid masonry unit of clay or shale, usually formed into a rectangular prism while plastic and burned or fired in a kiln. Brick is a ceramic product."[39] Historically, brick have long been manufactured locally in America, as the raw materials of clay and sand can be found everywhere.[40] Solid brick was the traditional structural masonry building material in New Orleans, as there was no local stone. Buildings seen in the earliest drawings show construction in wood, before brick was available locally. Stone or brick were not available in the lower Mississippi valley and along the Gulf Coast. As a result, a mixture of mud and moss called *bousillage*, and soft bricks or tabby, [the latter] a mixture of

[38] "ASTM C43," *1998 Annual Book of ASTM Standards* Vol. 04.05 (W. Conshohocken, PA: ASTM, 1998), 28.
[39] Ward Bucher, ed. *Dictionary of Building Preservation*, (New York: John Wiley & Sons, Inc., 1996), 65.
[40] Harley J. McKee, *Introduction to Early American Masonry, Stone, Brick, Mortar and Plaster* (Washington DC: National Trust for Historic Preservation, 1973), 41.

ground sea shell and water, were substituted.[41] In 1727, Marie Madeleine Hachard, a young Ursuline sister wrote of New Orleans:

> …very pretty, well constructed and regularly built … the houses are very well built of *colombage et mortier*. … The colonists substituted locally made soft brick for the stone and added clay mixed with Spanish moss as insulation – an idea borrowed from the Indians.[42]

Historical references differ slightly on the establishment of the first brickyard on Bayou St. John. According to Wilson, De Morand, acting Engineer of the City in 1726, had established the first brick yard in New Orleans in 1725, and eventually acquired its ownership.[43] According to Cizek, "The Company of the Indies opened the city's first brickyard in 1725, on Bayou Road."[44] In another reference, taken from the Mississippi Provincial Archives, "The first brickyard was established outside New Orleans on Bayou St. John in September, 1726, employing several white artisans and fourteen black workers. During its first twenty-five months of operation, the yard produced 400,000 bricks."[45] "About 1727, a second brickyard was established by the Jesuits outside New Orleans."[46]

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[41] Fred Daspit. *Louisiana Architecture 1714-1830*. (Lafayette, LA: The Center for Louisiana Studies, 1996), 5.
[42] Mary Cable, *Lost New Orleans*. (Boston: Houghton Mifflin Company, 1980), 7. Cable explains that *colombage et mortier* was a Colonial adaptation of a Norman construction method that traditionally combined stone and timber.
[43] Samuel Wilson, Jr. *The Vieux Carré New Orleans Its Plan, Its Growth, Its Architecture. Historic District Demonstration Study*, Conducted by Bureau of Governmental Research New Orleans. Louisican for the City of New Orleans, (1968), 23.
[44] Cizek, Eugene. "Beginnings." *Louisiana Buildings 1720 – 1940: The Historic American Buildings Survey*. Poesch, Jessie and Barbara SoRelle Bacot, eds. (Baton Rouge: Louisiana State University Press, 1997), 17.
[45] Mills Lane, *Architecture of the Old South: Louisiana*. (New York: Beehive Press, 1990), 23, quoting Dunbar Rowland and Albert Godfrey Sanders, *Mississippi Provincial Archives*, V, (Baton Rouge, 1984), 116.
[46] Ibid, 23.

Visitors to New Orleans often reported on the brick construction,[47] but it was not until the almost complete loss of wood buildings in the great fires of 1788 and 1794 that New Orleans became a city of brick. Laughlin described New Orleans architecture: "Known as *briquette entre poteaux*, it consisted of using a framework of timbers packed in between with soft bricks, and supporting a segmented tile roof, whose flashing and chinking was done with mortar … All walls were then plastered over to seal the bricks."[48] As a result of the 1788 fire, and another in 1795, Spanish authorities declared new building regulations for New Orleans. These regulations required that houses be built within the central fortified area and that:

> In order to prevent fires in the future … should all be constructed of brick or lumber and filled with brick between the upright posts, the posts to be covered with cement of at least one inch thick,[49]

The poor quality of the early New Orleans bricks and the necessity that they be protected from weathering by plaster has been highlighted by many writers. In 1913, Owen Allison told fellow architects what might be found in New Orleans:

> …he will find simple grace and dignity imparted with a master's skill to rotten, old, soft red brick made from the *batture* mud of the Mississippi, covered for the most part with stucco of lime obtained from the burning of oyster shells,

[47] Ibid, 26. Quoted Honoré Michel de la Rouvellière in 1752 and Philip Pittman in the 1770s. from *Philip Pittman, The Present State of the European Settlements on the Mississippi* (London, 1770), 42-43; David Lee Sterling, ed. "New Orleans, 1801: An Account by John Pintard." *Louisiana Historical Quarterly*, Vol. 34, No. 3 (July 1951), 230. John Pintard also commented on the brick buildings in New Orleans.
[48] Laughlin, C.J. "The Architecture of New Orleans" *Architectural Review* v. 100 (1946 Aug.): 35-36.
[49] Barbara SoRelle Bacot , "New Orleans After the Fires" *Louisiana Buildings 1720 – 1940: The Historic American Buildings Survey.* Jessie Poesch and Barbara SoRelle Bacot, eds. (Baton Rouge: Louisiana State University Press. 1997). 42; Lane, 26; and Samuel Wilson, Jr., "The Architecture of New Orleans." *AIA Journal*, (August 1959): 32-35. All have taken this quote from the *Records and Deliberations of the Cabildo, IV*. typescript, WPA, 1936.

> and in which are imbedded good old cypress beams as sound today as when first hewn.[50]

The soft river bricks, called simply "reds" by local masons, were not the only bricks used in New Orleans. Toward the middle of the nineteenth century, clay deposits of good quality were discovered on the bay coast at Ponchatoula and Slidell. Bricks made from this clay were hard enough to allow exposure, although they were usually also protected with stucco or painted.[51] These lake bricks are locally called "tans" and are often spotted with partially burnt iron impurities. Joseph Holt Ingraham writing in *The South-West by a Yankee* in 1835 described the parishes north of Lake Pontchartrain:

> They burn great quantities of lime from the beds of shells, which cover large tracts near the lakes; they also send sand from the beaches of the lakes, for covering the pavements of New Orleans. They have also, for some years past, manufactured brick to a great amount, and have transported them across the lake.[52]

Brickmaking was an important industry in New Orleans during the nineteenth century. According to Rightor's *Standard History of New Orleans*,

> Among the ante-bellum industries which did well in New Orleans because it did not pay to carry them on elsewhere, were naturally the building trades and the manufacture of building materials – brick, tile, lumber, etc. The brick was made almost exclusively in New Orleans, or at points across the lake in St. Tammany parish.[53]

[50] Allison Owen, "The Architectural Charm of Old New Orleans." *Journal of the American Institute of Architects*. vol. 1, (1913): 426.
[51] Samuel Wilson. Jr. and Bernard Lemann. *New Orleans Architecture Vol. 1 The Lower Garden District* (Gretna, LA: Pelican Publishing. 1971). 59.
[52] Ingraham, 275.
[53] H. Rightor. *Standard History of New Orleans* (Chicago: Lewis Publishing Co., 1900). 514.

New Orleans was also a busy shipping port and could import face bricks for important civic construction work. One customs manifest from 1821 to 1832 showed the importation of brick from Boston, Amsterdam, Antwerp, Philadelphia, Alexandria, Liverpool, New York, Genoa, Baltimore and Pensacola. The bricks imported included "35,000 bricks and freestone for Custom House 1/9/1821", "Fire" bricks, "Hard" bricks and "Blown" bricks.[54]

The tombs in St. Louis Cemetery No. 1 were based on the local brick building traditions, and all but two of the tombs surveyed are of local hand made orange-red river brick or tan and/or spotted lake brick. This tradition is further verified by the many historical references made by Benjamin Latrobe and other cemetery visitors in the nineteenth century to plastered brick.

As a construction material, brick served St. Louis Cemetery No. 1 well. Brick has high compressive strength (2,000 to 6,000 lb/sq. in. depending on mode of manufacturing) which can easily carry the load of the tomb structure and its minimal contents. Brick has low tensile strength, so must span voids in an arched or vaulted manner where tensile stress can be converted to compressive stress.[55] The tomb vaults were constructed in such a manner. However, there are flat roofs at considerable risk on tombs in the cemetery that do not have arched support.

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[54] *Customs Manifest* – Federal Archives, N.O., LA. Brick, 1/9/1821 to 7/5/1832.
[55] Cecil C. Handisyde, *Building Materials: Science and Practice* (London: Architectural Press, 1961), 66.

Brick has a low coefficient of thermal expansion as compared to lime or cement mortar, and as long as the clays are fully fired, the amount of expansion due to moisture absorption is negligible.[56] The slightly rough surface of handmade brick provided a good mechanical key to lock in bedding mortars and stucco coverings. The soft porous brick had high porosity and could adjust well to variations in capillary rise in ground water. Brick would absorb water in relation to their porosity, with lowest density brick absorbing more than higher.[57] The river "reds" were more porous and would be expected to absorb more moisture than the lake "tans" at St. Louis Cemetery No. 1.

Brick, and its deterioration, has been the topic of considerable research. Deterioration issues are mostly related to water; water eroding exposed, poorly fired areas of brick, water depositing salts within the pores from the soil or airborne pollution, water breaking down the adhesion between brick and mortar, or between brick and stucco, water related freeze-thaw damage, or water initiated corrosion of attached or embedded metal. Even with these deterioration risks, brick construction is very durable. According to one brick admirer, "It is well known that clay bricks are usually extremely

[56] Torraca, Giorgio. *Porous Building Materials: Materials Science for Architectural Conservation.* (Rome: ICCROM, 1981), 29. The thermal expansion coefficient for a common brick is $5 \cdot 10^{-6}$ vs. cement mortar at $10\text{-}11 \cdot 10^{-6}$ and a lime mortar at $8\text{-}10 \cdot 10^{-6}$: Robinson, Gilbert C. "Characterization of Bricks and their Resistance to Deterioration Mechanisms." *Conservation of Historic Stone Buildings and Monuments*, N.S. Baer, ed. (Washington, D.C.: National Academy Press, 1982), 157. Reports that the moisture expansion for brick is usually less than 0.04%.

[57] D. Hoffmann, and K. Niesel. "Moisture Movement in Brick." *Proceedings : In Vth International Congress on Deterioration and Conservation of Stone, Lausanne, 25-27.9.1985*, G. Félix, ed. vol. 1 (Lausanne, Suisse: Presses Polytechniques Romandes, 1985), 103.

durable and that although they may change in appearance after considerable exposure, they usually do so in a manner which is pleasant rather than otherwise."[58]

3.3.3 Mortar, Stucco, Plaster and Render[59]

Mortar, stucco, plasters and renders are all members of a group of adhesive mixtures containing compounds of lime, and certain allied compounds of magnesium, capable of uniting fragments or masses of solid matter to a compact whole which can be defined as calcareous cements.[60] Another, definition is that "mortars, plasters and renders are combinations of binder pastes and fillers, with or without fibrous reinforcements and are used in, or applied to, a wide variety of masonry and lightweight backgrounds."[61] The basic components are the binder paste, sand or aggregate, and water. The binder can be clayey soil, lime, hydraulic lime or cement.[62]

[58] Handisyde, 176.
[59] "Plaster" is usually a term reserved to describe a mixture used in the interior of a building, although in New Orleans, the term is commonly used to describe exterior coverings, such as those on the tombs at St. Louis Cemetery No. 1. "Render" and "stucco" are terms commonly used to describe mixtures for exterior coverings, with "render" being used more by the European community and "stucco" used more often in the United States. For this document, the term "stucco" will be used to describe exterior coatings, unless the term "plaster" is used in a historical quote, and the term "mortar" will be used to describe the mixture used in the construction of the brick wall, or for generic discussions of the class.
[60] F. M. Lea, *The Chemistry of Cement and Concrete* (New York: Chemical Publishing Company, 1971), 1.
[61] John Ashurst, *Mortars, Plasters and Renders in Conservation* (London: Ecclesiastical Architects' and Surveyors' Association, 1983), 9.
[62] In modern language, "cement" is generally understood to mean Portland cement. However, the term was used historically and depending on the term's use, it often meant the hydraulic binder.

In this research, it was of interest to consider the hydraulicity of the stucco binder, as the primary reactions and issues of lime, hydraulic lime and cement can contribute differently in certain decay mechanisms. It was also suspected that hydraulic limes were used in the exterior stucco at St. Louis Cemetery No. 1.

Lime is derived from the burning (calcination) of one of the naturally occurring forms of calcium carbonate, such as shell, limestone, chalk or marble. In a mortar mix, the calcium oxide carbonates through the loss of H_2O by a reaction with CO_2 in the air. This is a slow process and the full cure can take years depending on many factors such as the thickness of the wall, exposure to air, relative humidity of the surrounding environment and any surface coatings.

$CaCO_3$
Calcium Carbonate
or limestone, shell, marble, etc.

$\xrightarrow{\text{Calcination in a kiln at 880°C or above to drive off } CO_2\text{.}}$

CaO
Calcium Oxide
or Quicklime

The Quicklime is added to water – The process of Slaking

$Ca(OH)_2$
Calcium Hydroxide
or Slaked Lime

Upon exposure to air, Carbonation takes place. CO_2 is taken from the atmosphere

Hydraulic limes are those achieved from certain argillaceous or clay-based limestone. When burned, calcium silicates and calcium aluminates are produced in addition to the calcium oxide. Hydraulic limes are set by hydration, a chemical reaction with water,

and are referred to as "hydraulic" because of this fact. They also are called "hydraulic" for a second reason: when hardened, hydraulic lime mortars are water-resistant. The calcination process is similar to that for lime, except that kiln temperatures can be as high as 1200°C. The clay decomposes between 400 and 600°C and combines with some of the lime after 950°C. The calcination temperatures used in production, and the differing impurities found in argillaceous limestone, create a great deal of variation in hydraulic limes. Hydraulic limes are classified by their hydraulic ability as feebly hydraulic lime (<12% clay materials, sets in 15-20 days after immersion), moderately hydraulic lime (12%-18% clay materials, sets in 6-8 days after immersion) and eminently hydraulic lime (18%-25% clay materials, sets 2-4 days after immersion).[63] Natural cements are actually eminently hydraulic limes.[64]

Example of one hydraulic phase, dicalcium silicate.

$$2\ CaO{\cdot}SiO_2 + H_2O \rightarrow Ca{-}SiO_2{-}H_2O + Ca(OH)_2$$

$$Ca(OH)2 + CO2 \rightarrow CaCO_3 + H2O$$

$$CaO{-}SiO_2{-}H_2O + CO_2 \rightarrow CaCO_3 + SiO_2 + H_2O$$

Lime mortars can also be made hydraulic by the addition of hydraulic materials, pozzolans, like ground brick or volcanic material. The final reaction results are the same as for the hydraulic lime. "From a practical point of view, hydraulic mortars used since the middle of the 18th century and containing hydraulic lime do not show, chemically and once hydrated, any significant difference when compared with lime-

[63] The setting times are taken from L.J. Vicat, *A Practical and Scientific Treatise on Calcareous Mortars and Cements, Artificial and Natural.* Translated by Captain J.T. Smith, (1837 reprint, London: Donhead Publishing Ltd., 1997), 6-8.

[64] John Ashurst and Francis G. Dimes. *Conservation of Building & Decorative Stone.* (Oxford: Butterworth Heinemann, 1998), 81.

pozzolans mortars developed by the Romans, since the reaction products are the same."[65] Generally, there is no analytical need to distinguish a hydraulic lime from a lime mortar made hydraulic through the addition of hydraulic material. If so, optical microscopy is the best tool to observe the differences in the aggregate components.

Addition of pozzolans material to a lime mix.

$$CaO + H_2O \rightarrow Ca(OH)_2$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \text{ and } Ca(OH)_2 + SiO_2 + H_2O \rightarrow CaO\text{—}SiO_2\text{—}H_2O$$

$$CaO\text{–}SiO_2\text{–}H_2O + CO_2 \rightarrow CaCO_3 + SiO_2 + H_2O$$

The principal difference between natural hydraulic lime, or natural cement, and modern cement is in the temperatures of production.[66] To produce modern cement, the lime is burned well above the sintering temperature of around 1400°C, producing different hydraulic phases. The phase diagrams for cement are quite complex. As a gross simplification, the major hydraulic phase of cement is called C_3S ($3\ CaO{\cdot}SiO_2$), or alite, whereas the dominant hydraulic phase in hydraulic lime is C_2S ($2\ CaO{\cdot}SiO_2$), or belite. Also, because of the temperatures used in production, certain compounds, such as gehlenite, are no longer present in cement, and others would be found in very small quantities, such as free $Ca(OH)_2$ and calcite. Of the four major phases of cement, alite, (50-70%, tricalcium silicate), belite (15-30%, dicalcium silicate), aluminate (5-10%, tricalcium aluminate), and ferrite (5-15%, tricalcium aluminoferrite), each has distinctive

[65] Philippe Gleize, et. al., "Ancient Rendering Mortars from a Brazilian Palace: Its Characteristics and Microstructure," *Cement and Concrete Research* 30 (2000): 1613, quoting from M. Collepardi, "Degradation and Restoration of Masonry Walls of Historic Buildings," *Material Structure* 23 (1990): 81-102.

[66] Modern cement generally means Portland cement.

phase change temperatures and crystalline forms.[67] These small differences can be useful clues for a researcher analyzing for historic hydraulic lime.

As mentioned in the section on brick, the brickwork in New Orleans was usually covered with stucco. Speaking of New Orleans architecture of the mid-nineteenth century, Curtis and Spratling said in 1925 that the natural surface of brick was not left exposed and that there was a universal distaste for the red color of brick. "Perhaps experience had taught that the brick obtainable were apt to be porous, hence liable to become damp and mouldy [sic] and easily discolored."[68]

It is thought that due to the very wet climate in New Orleans, builders would have used hydraulic lime and natural cements in the nineteenth century. As early as 1703, Joseph Moxon advised that "lime made of hard Stone [containing clay], is fit for Structures, or Buildings, and Plastering without Doors or on the out side [sic] of Buildings that lie in the Weather."[69] In 1849, Joseph Gwilt discussed Smeaton and Higgens' work on chalk [pure lime] vs. stone lime [containing clay] with the aggressive conclusion that "there is no excuse for its [chalk lime] use and it should in sound building be altogether

[67] H.F.W. Taylor, *Cement Chemistry* (San Diego: Academic Press, 1990), 1-32.
[68] N.C. Curtis, and William P. Spratling, "Architectural Tradition in New Orleans." *The Journal of the American Institute of Architects,* Vol. XIII, no. 8 (August, 1925): 285.
[69] Joseph Moxon, *Mechanick Exercises or the Doctrine of Handy-Works*, 2nd ed., London (1703 reprint, Morristown, NJ: Astragal Press), 241.

banished." [70] Although no stone, clay containing or otherwise, available locally in New Orleans, the properties of "stone lime", or hydraulic lime would have been known to the cosmopolitan community of architects, and imported lime was available from the north. Natural cements, which are actually hydraulic lime, were first used on the Erie Canal in 1818, and by 1828 there were several cement works established in New York, Pennsylvania and Kentucky and product was shipped all over the developed part of the country.[71]

Yet, in a review of the writings of New Orleans historians and architectural historians, there is little to be found to describe the binder composition of the historic mortar and stucco mixtures. One local architect, Henry W. Krotzer, who read many of the archival journals of the early New Orleans builders and researched available work orders and receipts from projects that occurred in the mid 1800s, said that he found very little specific information in the documents.[72] One small reference to an estimate of required "Cement (Hydraulic) – 14,370 barrels, Lime – 9,646 barrels, Sand – 52,619 barrels and Shells – 18,818 barrels" was found in the Thomas K. Wharton journals along with several indications that he was specifying lake brick for the new Customs House in 1854.[73]

[70] Joseph Gwilt, *The Encyclopedia of Architecture: The Complete Guide to Architecture, from Antiquity to the Nineteenth Century*, (1867 reprint, New York: Bonanza Books, 1982), 533.
[71] McKee, 68.
[72] An interview with Henry W. Krotzer, March 20, 2002.
[73] Samuel Wilson, Jr. ed. *Queen of the South: New Orleans, 1853-1862 Journal of Thomas K. Wharton*, New Orleans: Historic New Orleans Collection and NY Public Library, 1999), 22, 32, 266.

Portland cement was also widely used at St. Louis Cemetery No. 1. The history of Portland cement begins in 1824 with Joseph Aspdin's patent on new and improved cement, called "Portland" because it resembled color of stone from Isle of Portland. The manufacturing of Portland cement began in the United States in the 1870s, in several locations. The industry grew rapidly. By 1878, there were 28,000 barrels reported to have been manufactured in the U.S. and by 1896, 1,543,023 barrels were reported.[74] By 1937, 118,000,000 barrels were produced in the United States.[75]

When analyzing historic materials, it is important to realize that the change to Portland cement did not happen all at once, but as a gradual evolution. The historic hydraulic limes, natural cements and early manufactured cements will all have similarities, particularly when mixed with local sand. The modern Portland cement mortars are made of materials that have been produced in very controlled and standardized processes and the differences seen in analytical techniques will be quite clear, and might not be representative of an earlier production time, so current cements are not good standards to use in historic mortar analysis.[76]

[74] Jasper O. Draffin, "A Brief History of Lime, Cement, Concrete and Reinforced Concrete" *Journal of the Western Society of Engineers* Vol. 48 No. 1 (March 1943): 5-37. He reports the data from Uriah Cummings, *American Cements* (1898), 289.
[75] Draffin, 13, He reports this data from *Cement and Concrete: A General Reference Book*, (Portland Cement Association, 1941).
[76] K.J. Callebaut, et. al., "Nineteenth Century Hydraulic Restoration Mortars in the Saint Michael's Church (Leuven, Belgium) Natural Hydraulic Lime or Cement?" *Cement and Concrete Research* 31 (2001): 403.

The topic of historic mortar analysis and deterioration is a large and complex area of research. As in brick, most of the deterioration processes take place triggered by water. From ancient history, stucco has often been used with a full understanding that these processes will take place, and that they will take place most efficiently at the exterior surface. If the masonry is covered with stucco as a sacrificial exterior layer, the replaceable stucco will absorb the bulk of the damage, leaving the inner core safe. This logic holds, as long as the stucco layer is renewed periodically as it loses its functionality and becomes too deteriorated.[77]

Considerable research has been directed to the topic of replacement mortars and stucco, as can be seen by many of the article titles in the bibliography at the end of this thesis. During the mid-twentieth century, war damaged resources in Europe were reconstructed using Portland cement, and the heavy use of Portland cement continued for restoration projects well into the 1970s. The rate of deterioration was much greater than had been expected, and research projects soon identified the major causes. According to the concluding summary on historic mortars at the 2000 RILEM Workshop: "There is general agreement that the use of highly hydraulic cement based mortars for restoration and renovation has caused extensive damage to cultural heritage."[78]

[77] Torraca, 108-109.
[78] Caspar J.W.P. Groot, Peter J.M. Bartos and John J. Hughes. "Historic Mortars: Characteristics and Tests – Concluding Summary and State-Of-The-Art." *International RILEM Workshop on Historic Mortars: Characteristics and Tests, Paisley, Scotland 12th-14th May 1999*, P. Bartos, ed. (Cachan France: RILEM Publications, 2000), 450.

The objections to the use of eminently hydraulic limes (natural cements), and especially Portland cement, are based on their high strength, more impermeable nature and the risk of transferring soluble salts to vulnerable masonry materials. Their adhesion properties are usually too good, particularly to old masonry, and their thermal expansion is often as much as twice as great. Any weakness caused by material movement will be transferred to the weaker material, and the stress will damage or break the historic material.[79] By being less permeable, OPC (ordinary Portland cement) will drive moisture in the direction of the more porous masonry, again forcing the deterioration mechanism to take place most aggressively in the historic material.[80] It is now generally accepted conservation practice that repair mortars should exhibit properties already present in the *in-situ* material; must be compatible given the surrounding environmental factors; must be appropriate to the state of conservation (or deterioration) of the existing structure, especially for any damaging processes already in place; and must be suitable for the function of the mortar or stucco application under consideration.[81]

[79] Torraca, 80.

[80] David Carrington and Peter Swallow. "Limes and Lime Mortars – Part Two." *Journal of Architectural Conservation*, No. 1 (March 1996): 7-22.

[81] Rob P.J. Van Hees, "Damage Diagnosis and Compatible Repair Mortars." *International RILEM Workshop on Historic Mortars: Characteristics and Tests, Paisley, Scotland 12th-14th May 1999.* (Cachan, France: RILEM Publications, 2000), 27-35.

3.3.4 Surface Finish

The traditional St. Louis Cemetery No. 1 surface finish was lime wash. Limestone, or calcium carbonate, was calcined to decompose into calcium oxide, which, when immersed in water, hydrolyzed to calcium hydroxide. This material went onto the stucco as lime wash. As it dried, the calcium hydroxide reacted with the carbon dioxide in the air to reform as a new crystalline form of calcium carbonate, or calcite. The calcareous nature of lime based paints results in a coating of low opacity, creating the characteristic surface glow associated with lime washed surfaces. This effect has never been exactly duplicated in modern paint products.

The lime served the purpose of filler and base pigment, although evidence exists that other tinting pigments were sometimes added. Through archival accounts and through modern microscopic cross- sections, we can verify that the tombs of St. Louis Cemetery No. 1 were often surfaced in earthen colored lime washes. The lime acted as the binder, forming a porous inorganic ionic crystalline structure which bound up any additional colorant (pigment) and provided body. The resultant crystalline structure was breathable and allowed continued carbonation of the much thicker stucco layer

beneath. Lime wash was also mildly antiseptic, a useful temporary defense against bio-growth.[82]

Lime wash was not a long-lasting material and traditionally was reapplied every 1-3 years. It wore off by very fine losses as the crystalline bonds broke, a type of weathering deterioration that many find less objectionable than the blistering and peeling of modern latex paints. The purpose of the finish, beyond its decorative appeal, was to help the highly porous surface of the stucco shed water and resist biological growth. Surface finishes kept biological organisms from attaching to the rough stucco, directed water down the tomb and away from the structure and minimized water adsorption on the stucco surface. The finish would not be able to stop water absorption once liquid water reached the stucco and interior materials through either the capillary action of rising damp, or water leakage through cracks and openings in the system. Once that occurred, a modern non-breathable finish would do greater harm by making the desorption processes more difficult.

The application of hydrophobic or waterproof finishes was an exercise in futility in this moist environment. The use of such a treatment assumed that all pores in the hydrophilic solid could be treated by deep impregnation, which did not generally

[82] Ashurst, John and Francis G. Dimes. *Conservation of Building & Decorative Stone* (Oxford: Butterworth Heinemann, 1998), 229.

happen with available application techniques. Modern hydrophobic films are organic and subject to oxidation. They break down chemically with time and through UV degradation. As the film decomposes, color changes, usually to a yellow cast, and strength decreases. Water accumulation behind the film creates more problems, as water will eventually find a way into a very porous material by way of rising damp or micro cracks which will eventually develop in the surface finish or at construction joints.[83]

3.3.5 Additional Components

St. Louis Cemetery No. 1 offers many topics for research. The additional tomb components of marble, used for the closure tablet system, sculptural elements and limited tomb cladding, as well as the metalwork, used decoratively and for enclosures, were not included in this research. They also have experienced deterioration and many of the decay mechanisms discussed herein can also relate to these materials, since most deterioration is caused or exacerbated by exposure to moisture. Material properties and mechanical attachment issues differ, however, and further research on these materials is warranted.

[83] Torraca, 117-118.

3.4 Environmental Conditions

3.4.1 The Environment of New Orleans and the Cemetery Site

Fig. 3.6 Flooding between the tombs, Oct. 2001.

As mentioned in Chapter 2, the environment and the constant battle to keep New Orleans dry feature largely in the history, culture and practices of the city. It is easy to believe the graphic historical accounts of watery graves and miasmic soil during any visit to St. Louis Cemetery No. 1 during a heavy summer downpour.

According to Rightor, "New Orleans is situated in a marsh. Its greatest natural elevation above the sea level is 10 feet 8 inches, which is artificially increased to 15 feet by the levee on the river bank. …it being impossible to dig three feet without striking water. Under these circumstances it is readily seen that burial, as understood in more elevated localities, is out of the question in New Orleans."[84] A modern New Orleans engineer described the city's topography as plates formed with sectioning

[84] Rightor, 256.

ridges. The ridges are 10-15 feet above sea level, but the heavily developed areas between are below sea level.[85] All water that enters must be pumped out. With heavy rainfall of 57 inches per year and the mighty Mississippi river surrounding most of the city, controlling water, particularly flood water, is very critical. The New Orleans pumps have a total capacity of 42,000 cubic feet per second or a little over a billion gallons per hour during rain load.[86]

It is commonly believed that parts of New Orleans are sinking. Janssen reported on a study of fifteen permanent benchmarks (US Coast and Geodetic Survey marks, Louisiana Geodetic Survey, New Orleans Sewerage and Water Board, US Army Corps of Engineers) over 26 years. The results and his own calculations led Janssen to conclude that the average subsidence of the ground level is 1.12 ft, or 0.043 (approx. ½ inch) per year.[87] In another article, he reported that stepped-brick spread footings were popular in French Quarter construction and piling was apparently not used. He assessed settling of buildings in the French Quarter as fairly even, with a general downward movement without failure or major cracking of walls.[88]

[85] James S. Janssen. James S. "Draining New Orleans" *Building New Orleans: The Engineer's Role. A Collection of Writings.* (New Orleans: Waldemar S. Nelson & Co. 1987). 23.
[86] "The Pumps that Keep New Orleans Dry." *Water Engineering & Management,* (9/1/1999).
[87] James S. Janssen, "Changes in Elevations in the New Orleans Area", *Building New Orleans: The Engineer's Role. A Collection of Writings.* (New Orleans: Waldemar S. Nelson & Co. 1987). 18-19.
[88] James S. Janssen, "Early Masonry in Nouvelle Orleans – Was Brick the Answer?" *Building New Orleans: The Engineer's Role. A Collection of Writings.* (New Orleans: Waldemar S. Nelson & Co. 1987). 71.

A different type of subsidence is believed by many to be occurring at the site. The partially buried lower vaults in St. Louis Cemetery No. 1 are often offered as proof of this subsidence, with the assumption that the heavy brick structures are sinking into the marshy soil. Not enough research has been done to verify this as a fact, and the historic practice of adding shell and dirt fill to the cemetery paths to make passage easier during rainy seasons has certainly played an additional role in the height of the ground at the tomb bases.

New Orleans, at Latitude 29.59 and Longitude 90.15, is not as hot as many perceive. High humidity in the hottest months makes the temperature feel higher than actual. The average temperature from May through September is 80.4°F, yet from October through April, it is very pleasant at 62°F on average. The temperature only rises above 95°F about 6 days a year, but rises above 90°F between 16-21 days in June through August. For most of the year, residents and tourists are quite comfortable. Freezing weather is rare. The highest winds average about 43.6 mph during the year, except in the September hurricane season where the average is 69 mph. There is usually at least one hurricane per year during that season. The rainy season is June through August with 12 - 13 days of rain per month and total days of rain are 114 per year.[89]

[89] *Comparative Climatic Data Report for the U.S. Through 1999.* Congressional Information Service, Inc. 2000. Additional facts taken 6/02 from NOAA website at www.noaa.gov.

According to the 1989 Soil Survey of Orleans Parish, St. Louis Cemetery No. 1 is located in land classified as Urban Land. Urban Land consists of areas where more than 85 percent of the surface is covered by asphalt, concrete, buildings, or other impervious surfaces.[90] The soil of the cemetery has a black clay surface layer about 6 inches thick. This soil contains a large quantity of shell and shell fragments from the original paving materials. Historically, the groundcover of the cemetery was volunteer grass and the paths were shell, but a majority of the surfaces are now covered in asphalt, or more recently, concrete paving. Slope throughout the site was measured during the *Survey* to be less than 1 percent.

3.4.2 Biological and Vegetative Growth

The basic requirements for bio-receptivity include an availability of surface on which they can get anchorage; enough nutrients to sustain their development and growth; and adequate amounts of water to support their main physiological functions and, in many cases, their multiplication and dissemination. The rough surfaces and porous micro-cracked structures of the stucco, mortar and brick, are very conducive to the initiation and growth of the organisms of both the photosynthetic type that require sunlight, and the chemosynthetic type that can survive without sunlight.[91]

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[90] *Soil Survey of Orleans Parish* (Washington: USDA, 1989).

[91] Rakesh Kumar, *Biodeterioration of Stone in Tropical Environments* (Los Angeles: Getty Conservation Institute, 1999), 4.

The growth process moves from small cell organisms to higher level plant life. Cyanobacteria and green algae are the first to colonize. They make a continuous bio-film that thickens as the numbers of species increase. As new taxa appear, the green algae decrease and a stratification of different species is established. When the bio-film layer is thick enough (about 100 μm), spores of mosses can germinate. These spores develop protonemas, which can turn into leafy stems after a few weeks. By this stage, hygrophilous species begin to take hold, humidity in the micro-environment increases, and higher forms of flora are possible, particularly so if there are cracks in the stucco or brick joints where humus has accumulated.[92]

The expansive growth nature of these organisms exacerbates all of the decay mechanisms discussed herein. Most of the real damage is caused by biophysical deterioration by the growing organism. Cracks are pushed open, adhesive bonds are ruptured and delamination happens more rapidly. As higher order organisms and root systems develop, whole-scale detachments occur and individual materials can be broken, crushed and forced apart. Biochemical deterioration, where the organism produces corrosive acids and enzymes that damage the substrate material, or where the organism uses material minerals from the substrate as a source of nutrition, also occurs at St. Louis Cemetery No. 1, but is not a major cause of decay.

[92] O. Guillitte, "Bioreceptivity and Biodeterioration of Brick Structures," Conservation of Historic Brick Structures, ed. N.S. Baer, et. al. (Dorset: Donhead, 1999), 70.

The bio-growth organisms and higher vegetation are also damaging aesthetically, as they create soiled surfaces, mask original details and detract from the original design intent of the structure. This visual damage is subjective, and viewers differ in their perception of what amount of biological growth is considered "patina" before being considered objectionable.

3.4.3 Other Environmental Issues

Two additional issues, traffic vibration and the impact of tourism could be considered in the larger environmental context. They could also be considered people issues. Most studies show that vibration stress is not sufficient to cause damage to a structure when considered alone, and in general does not represent an immediate hazard to structures.[93] Vibration is most damaging on small elements, particularly those furthest from a restraining structural member. Attached decorative elements meet these criteria, as does an outer layer of stucco. Vibrations of small amplitude, repeated in many cycles over time, can weaken the adhesion between materials and can contribute to the eventual detachment of the furthest elements. Vibration can also exacerbate problems caused initially by other causes. Cracks may have been formed through shear or tensile stress caused initially by a material's response to moisture. Vibration

[93] Kumar, p. 50; Handisyde, 33; N. Augenti and P. Clemente, "Strength Reduction in Masonry due to Dynamic Loads," *Proc. IABSE Symposium Extending the Lifespan of Structures, San Francisco*, vol. 2 (Zurich: IABSE, 1995), 1375-80; Paolo Clemente and Dario Rinaldis, "Protection of a monumental building against traffic-induced vibrations," Soil Dynamics and Earthquake Engineering 17 (1998): 289-296.

can then cause a widening of the crack, allowing in more water and debris, expanding the impact of the continuing moisture initiated decay mechanism.

Increasing tourism also threatens St. Louis Cemetery No. 1. An increase in use can be damaging to the physical fabric of the site with additional traffic on the paths, handling of tomb elements, uneven physical stress by those standing on the tombs, and litter. The garbage, loud tour guides and crowds threaten the park setting and atmosphere for quiet reflection and contemplation. Yet, tourism keeps crime and vandalism at the site to a minimum; it keeps the site active; it provides a forum that can be used to educate the outsider as to the history of a place and a culture; and it brings money into the city's economy.

Since the early years of its existence, outsiders have been drawn to this place of mystery, and this magnetism continues today. Tourism is as much a part of the history of the cemetery as is the construction of the tombs themselves, for as soon as this place was brought to life in physical form, it was borne into the visitor's imagination.

Though many do not wish to admit it, tourism is one of the principal reasons for which an attempt is being made to preserve this site. Outside interest creates local interest, which hopefully will induce a greater interest in preservation. Local grant assistance and state and federal funding for conservation efforts only become available to sites

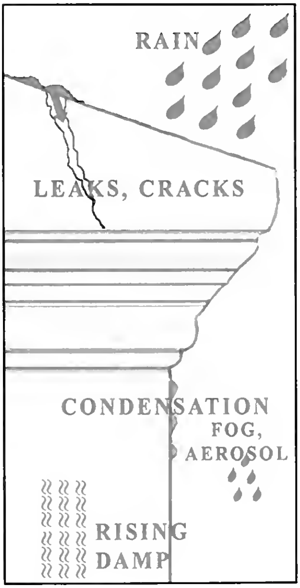
that can demonstrate consumer interest and outreach programs. When considered in this larger context, and when managed correctly, tourism is a valuable tool for the conservation of the physical fabric of the tombs, and the preservation of St. Louis Cemetery No. 1 as an irreplaceable cultural landscape.[94]

Fig. 3.7 St. Louis Cemetery No. 1, March 2001.

[94] L. Meyer and J. Peters, "Tourism – A Conservation Tool for St. Louis Cemetery No. 1" unpublished paper (May, 2001).

3.5 Moisture Driven Decay Mechanisms

In the above discussion of construction, materials and environment, the concepts of moisture movement and moisture driven decay mechanisms are often referenced. As stated by Trechsel: "It is generally accepted that well in excess of 75% (some estimates being over 90%) of all problems with building envelopes are caused to a greater or lesser extent by moisture."[95] Given this fact, and the moist climate at St. Louis Cemetery No. 1, an understanding of moisture driven decay mechanisms is critical for the interpretation of laboratory results.



Water is delivered to the tombs in St. Louis Cemetery No. 1 through direct rainfall penetrating a structure, through faulty rainwater disposal (as in design elements or cracks that direct water to the interior structure), through rising damp from ground held water, and through condensation and absorption of moisture vapor held in the air as humidity, or liquid droplets as fog or aerosol.

Fig. 3.8 Sources of moisture.

[95] Heinz R. Trechsel, ed. *Moisture Control in Buildings. ASTM Manual Series MNL 18*. (Philadelphia: ASTM, 1994), 35.

Connolly lists the following deterioration mechanisms caused by, or exaggerated by, inadequate moisture control:[96]

Table 1
J. D. Connolly's List of Deterioration Mechanisms Caused By Inadequate Moisture Control

Hydrolysis	Osmotic pressure
Alkali-silica reactivity	Delayed ettringite formation
Cyclic freeze/thaw degradation	Micro-organism attack
Vapor pressure	Rising damp
Salt migration/efflorescence	Corrosion (oxidation
Hydroscopicity	Dissolution
Wetting and drying	Dehydrohalogenation
Plasticizer migration	

3.5.1 Porosity and Moisture Movement

A review of the porosity of crystalline solids and methods of moisture transport serves to illuminate how all these mechanisms can be possible due to water. A material is porous when it contains interstitial spaces between micro-units (crystals) that are greater than normal atomic dimensions so that foreign molecules, such as water, can penetrate them.[97] Deterioration occurs because of either a physical or chemical incompatibility between two materials, or between a material and an externally applied

[96] J.D. Connolly, "Humidity and Building Materials" *Bugs, Mold and Rot II, Proceedings of a Workshop on Control of Humidity for Health, Artifacts and Buildings*, (Washington, DC: National Institute of Building Sciences, 1993), 29-36.
[97] P. J. Sereda, "The Structure of Porous Building Materials." *Canadian Building Digest 127*, (July 1970): 3.

force.[98] In non-porous materials, such stresses are limited to the external surface. In a porous material, the incompatibilities can impact the surface and build up pressure within the material by impacting on the interior surfaces of the pores. Whether the impact initially comes from a physical or chemical action, the internal action becomes mechanical stress causing the small pore structure to move to relieve the stress, eventually resulting in a crack.

Materials seek to relieve stress or pressure, on the macro, micro and atomic levels. This can be illustrated in the movement of water through a porous structure. The brick, mortar and stucco in this research are all crystalline porous materials made up of carbonates, silicates, aluminates and/or oxides. All of these crystals are oxygen rich and carry a negative charge, creating polar surfaces. Polar surfaces are considered hydrophilic (water loving) as they attract

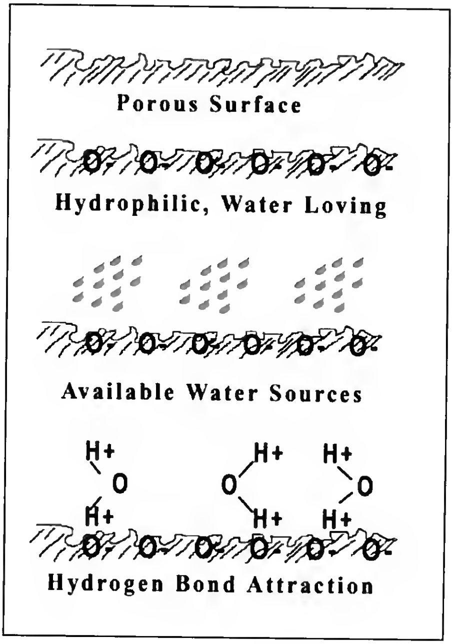


Fig. 3.9 Attraction of water molecules to hydrophilic porous materials. Adapted from Torraca.

[98] Alan Olivier, *Dampness in Buildings*, 2^{nd} ed., Revised by James Douglas and J. Stewart Stirling. (London: Blackwell Science, 1997), 9.

the positively charged hydrogen atoms of the water molecule, creating hydrogen bonds between the material and water. Being bound to the water is the more comfortable state on the atomic level. This strong attraction to water occurs on the surface of the porous material and inside all the surfaces of the pores, creating a powerful pull for water molecules in the vicinity to cover up a molecule of material surface. As each molecule of water is bound, more follow, since water also is attracted to itself. This attraction on the molecular level begins to explain the absorption capability of these materials.[99]

If water is in a liquid state, it first moves through the porous material through capillary action, which can also be described by the attraction of water molecules to the material's hydrophilic surface. The skin of the water, called the meniscus, is filled with water molecules presenting their H^+ ends to the polar substrate. The smaller the pore, the stronger will be the capillary pull. As an example, water will rise 31mm in a 1 mm tube vs. 154 mm in a 0.2 mm tube under laboratory conditions. In the small pores within a brick, capillary movement can easily overcome the force of gravity.[100]

If the attraction of the polar surface to water molecules were the only transport mechanism at work, materials would fill and stay perpetually wet. However, the reality is a dynamic situation with both material and water always changing to reach their most comfortable states. Liquid water can move through a porous material by

[99] Torraca, 2.
[100] Giovanni Massari and Ippolito Massari. *Damp Buildings Old and New*. (Rome: ICCROM, 1993), 7.

diffusion, moving from the higher water concentration to a lower concentration, a less stressful state. Vapor diffusion occurs as water molecules move from air containing high levels of water molecules (high vapor pressure or high relative humidity) to a region of low water molecules (low vapor pressure, dry air or dry part of the porous material), which is how porous materials absorb water molecules from an atmosphere of high relative humidity. With heat, water moves from the warmer to the cooler region to be at a more stable state.

Another vapor state movement is called condensation, and is when the surface of a material is cooler than the dew point of the surrounding air. The water molecules can exist as vapor in the air at the given temperature and relative humidity, but will join together and coalesce into a liquid on the cooler surface. The molecules first adsorb onto the surface, and then will begin to be absorbed by the material if conditions are favorable. Adsorption is the process by which fluid molecules are concentrated on a surface through physical and/or chemical forces.[101]

[101] Trechsel, 36.

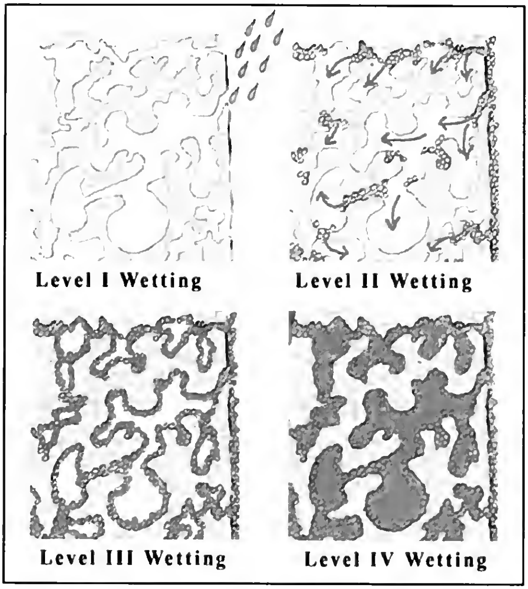


Fig. 3.10 The 4 levels of wetting for a hydrophilic porous material. Adapted from Torraca.

Figure 3.10 shows the 4 Levels of wetting as described by Torraca.[102] Level I is the dry state where the material surface and the interior surfaces of the pores have O^- molecule ends waiting for the H^+ ends of a water molecule. Water will distribute through a porous material first by capillary transfer, then by diffusion. It will fill the small capillaries first, as seen in Level II, and will coat the walls of the pores, as seen in Level III, before beginning to fill the cavities and larger voids. The term "critical water content" is often used to describe the point at which all small capillaries are filled and the pore surfaces are covered. At this point, water movement changes from vapor absorption and capillary pull or suction to the slower diffusion of liquid water through the pore spaces in the wetting process.

[102] Torraca, 12.

When graphed as amount absorbed per unit surface (m) vs. the square root of time, as in Figure 3.11, this section of the absorption curve flattens out. The relationship of water absorption follows the law $m = A\sqrt{t}$, where m is the amount of water absorbed per unit surface and A is the slope of the first part of the absorption curve, or the Capillary Absorption Coefficient. An analogous formula to describe the penetration depth into a material (X) is $X = B\sqrt{t}$ and X is proportional to the square root of time (t). In this formula, B is called the water penetration coefficient and is also the slope of the first part of the curve. These coefficients establish the property of the hygroscopic behavior of a material. A comparison of the coefficients of each material in a composite structure highlights incompatibilities in how free water progresses, or is inhibited, within the total system.[103]

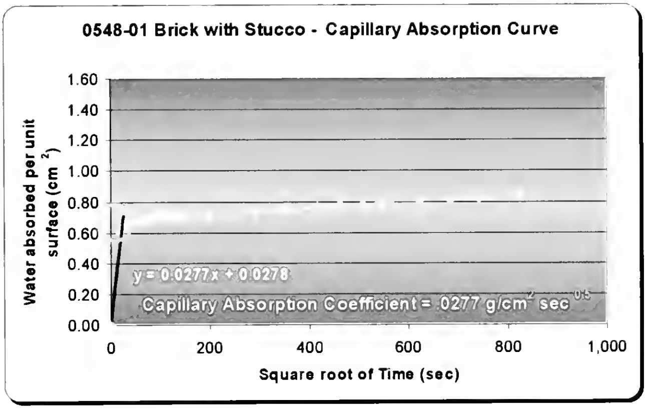


Fig 3.11 Capillary Absorption Curve for 548-01 Brick with Stucco.

[103] B.H. Vos. "Water Absorption and Drying of Materials" In *The Conservation of Stone I, Proceedings of the International Symposium, Bologna, 19-21 June 1975*, R. Rossi-Manaresi, ed., (Bologna: Centro per la conservazione delle sculture all'aperto 1976), 684. The water penetration coefficient and rising damp is further discussed in B. H. Vos, "Moisture in Monuments." *Application of Science in Examination of Works of Art*, William J. Young, ed. (Boston: Museum of Fine Arts, 1970): 147-153.

3.5.2 The Evaporative Drying Process

Moisture can enter a porous solid in both the vapor and liquid stage, but primarily leaves only through evaporation in the vapor stage. Here again, the drive to move to a more comfortable state has to exist for the water to move. When a wet surface is exposed to dry air, water leaves to move to a state of low water molecules and desorption or drying begins to occur. Since only a small portion of the water covered surfaces in a porous material are actually exposed to the dry air, this process can be much slower than the wetting process. Evaporation works best when the air is significantly less than 100% RH. In the tiny micro-environment of a wet pore, the environment stays at the 100% RH state and there is no internal drive to move the water. The point where drying by evaporation slows down is called the "critical water content" or bending point. RILEM calls it the "Knickpoint."[104] At this level, diffusion has stopped and the material's capillary conduction properties take over, as the small pores hold onto water molecules based on the oxygen to hydrogen attraction, making it difficult to fully dry the material.[105]

[104] RILEM Test No II.5 Evaporation Curve. This is the same state seen in wetting when just the pore surfaces are covered in water. See Level III in both the wetting and drying sketches.
[105] Massari and Massari, 26-30.

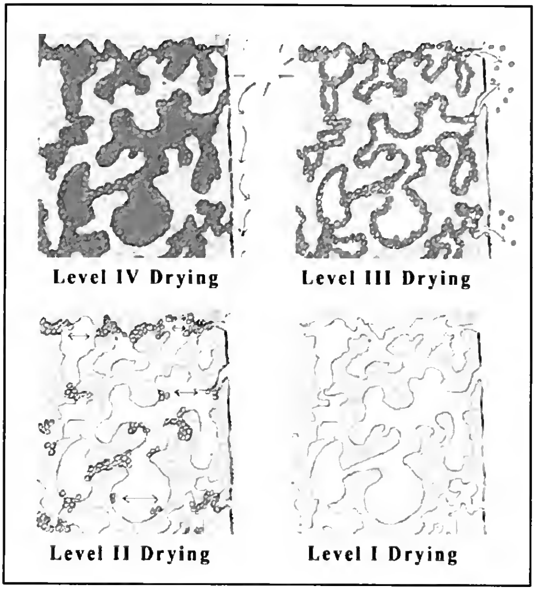


Fig. 3.12 The 4 levels of drying for a hydrophilic porous material. Adapted from Torraca.

Torraca used the same 4 level diagram to describe the drying process, adapted here in Figure 3.12 to show the differences in the direction of moisture movement. The dry air has caused the surface held water to evaporate in Level IV, and this evaporation continues as water in the liquid state moves to the surface and molecules near the surface evaporate. However, once the open spaces empty of liquid water, the process has very little initiative to move beyond Level III, or the point of critical moisture content.

When the drying rate curve of relative moisture lost per time ($\Delta Y/\Delta t$) is plotted against moisture content ($\Psi g/cm^3$), this change in drying rate can be seen. To fully dry out the material, more energy, such as heat, wind and/or a lot of time will often need to be applied externally to drive the water out through evaporation. When comparing materials, the

lower this number is, the longer is the period where the diffusion process is still occurring and the easier it is to dry the material.[106]

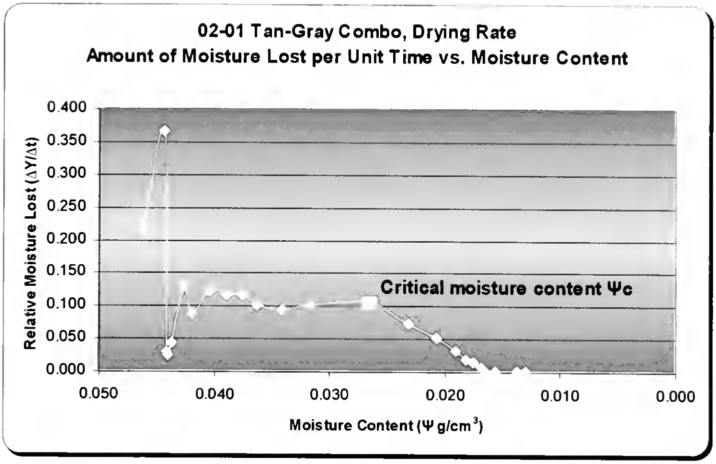


Fig. 3.13 Drying rate curve shows critical moisture content point.

Different materials will all have similarly shaped multi-stage absorption and drying curves, but will differ in rates and intensities of moisture movement and phase change depending on specific properties, such as porosity and chemical composition. The graphing of these moisture relationships helps to identify how materials will interact together when joined by an adhesive bond, and whether their combination will assist or restrict water movement.

[106] Vos, "Water Absorption and Drying of Materials," 690.

Depraetere and Hens described the interface between dissimilar materials as one of three types. A hydraulic contact exists where the pores match up and there is a continuity of capillary pressure and moisture flow across the interface. This situation can exist with a replacement stucco which has been very closely matched to an original layer *in-situ*. For many interfaces, there is actually air space along the bond, leading to a discontinuity in moisture movement. In the natural contact, there is good physical contact and adhesion, but the pores are different in size, or miss each other, also causing discontinuities in flow. In most cases of multiple stucco layers, they bond to brick and mortar, or contain micro-cracks between the layers and there will be a combination of air space and natural contact interfaces.[107]

The tombs at St. Louis Cemetery No. 1 have ready access to moisture from falling and wind-driven rain, leaks from existing micro and macro-cracks, rising damp from the ground moisture and condensation and absorption from the moist air. The above discussion describes the various mechanisms that allow the moisture to move through the materials. Given the moisture availability and its movement, deterioration actually occurs through chemical and physical means, often by both processes occurring together.

[107] W.J. Carmeliet Depraetere and H. Hens. "Moisture Transfer at Interfaces of Porous Materials: Measurements and Simulations." *International RILEM Workshop on Historic Mortars: Characteristics and Tests, Paisley, Scotland 12th-14th May 1999.* (Cachan, France: RILEM Publications, 2000), 256.

3.5.3 Chemical Actions

Moisture is required for any of the chemical actions that cause deterioration in building materials.[108] Moisture carries existing salts into solution, and enables many reactions such as the formation of expansive gypsum or ettringite. Moisture moves salts in solution through the porous structure. When the water de-sorbs by evaporation, the salts remain in the pore and re-crystallize, usually in a larger, non-elastic form and the physical damage process begins. The small pore moves to relieve the stress of the large salt crystals, and small micro-cracks occur. Micro-cracks, with their very fine diameters, have strong capillary suction, pulling in more salt-laden water the next time it becomes available, and the process continues with each re-crystallization of new salt forcing the cracks to grow

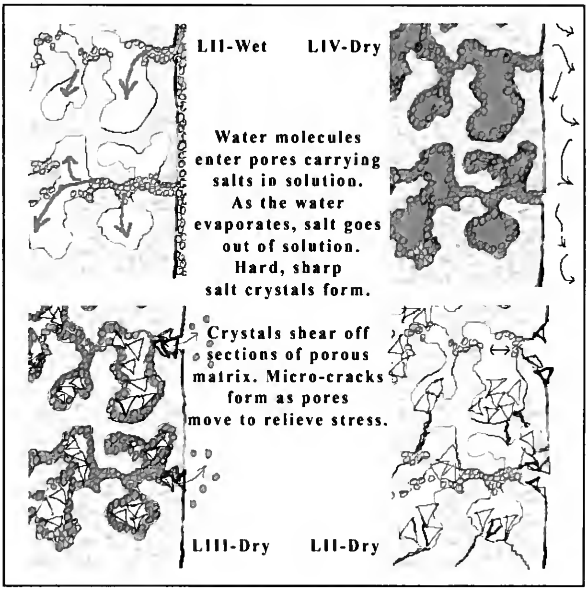


Fig. 3.14 The salt decay mechanism is a progressive mechanism, causing greater decay the more cycles the material experiences.

[108] Oliver, 9.

and more small cracks to form. The repeated cycling between wet to dry is much more damaging than if the material stayed perpetually wet with the salt remaining in solution.

The salts are generally more hygroscopic than the porous building material, and will raise the absorptive property, pulling in more salt-laden water to continue the cycle. At the interface between materials, as in the bond between stucco and brick, this damage process eventually breaks the adhesive bond and delamination can occur.

If the adhesive bond between materials, such as cement stucco and brick, is too strong, the stress will be relieved by a rupture in the weakest material, such as the result seen when the cement stucco pulls off a layer of the soft brick.

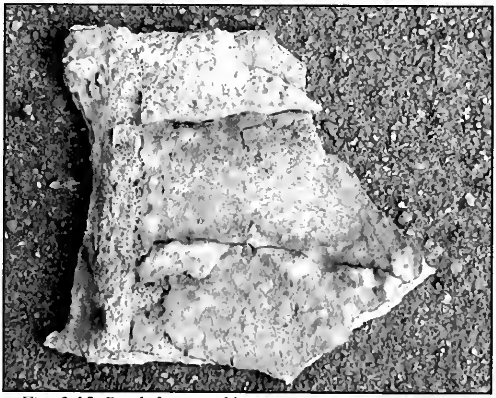


Fig. 3.15 Brick fractured by cement stucco. This is a sample from Tomb #275 where a new layer of cement stucco had been applied directly to the brick in locations where the old stucco had delaminated.

Rain water is slightly acidic because of the dissolved carbon dioxide from the air. This weak carbonic acid reacts with the carbonates of calcium and magnesium, found in mortar, stucco, limestone and marble to form bicarbonates, which are slightly soluble in water and will slowly dissolve.[109]

[109] Torraca, 38.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

$$2\,H_2CO_3 + CaCl_2 \rightarrow Ca(HCO_3)_2 + 2HCl$$
(one of the many possibilities)

If pH is higher, the carbonic acid converts to water and gives off CO_2, which also causes stress inside a small pore.

Water also enables the reactions that convert sulfur dioxide found in pollution into sulfuric acid, and oxides of nitrogen and other pollutants into nitric, hydrochloric and additional other acids. These strong acids deteriorate both carbonates and silicates.

$$SO_2 + H_2O + O_2 \rightarrow H_2SO_4$$

Here again, the wet / dry cycle accelerates the damaging effects. When wet, a structure can be coated in a thin film of water filled with salts and pollutant, giving the porous material the time to absorb the damaging materials. As the material dries and the water is desorbed, the salts and pollutants remain behind to initiate damage.

3.5.4 Physical Movement

As chemical deterioration occurs, there are physical stresses set up within the pores. These physical stresses eventually lead to cracks and broken bond adhesion, as the materials move to relieve the stress. In addition to the foregoing reasons for movement, displacement also can be due to load-bearing non-uniformities in the soil. The composition of soil, in terms of gravel, sand or clay, also affects its absorption of

water. Clay is the most absorbent. Clay is composed of highly absorbent particles arranged in stacks of hundreds of crystalline plates that slip and slide over each other when saturated with water. Good building design requires footings sunk beneath such a layer, but at St. Louis Cemetery No. 1, most of the tombs rest on a layer of black clay. Tomb settlement is evident where heavier tomb mass has sunk eccentrically relative to threshold. Differential movement in the soil can create shear stress in the tomb structure, with the weakest bonds cracking first to relieve such stress. Cracking will occur first in the stucco layer. Where it is closely bonded to the main structure, the rigidity of the finish will determine whether and how much cracking will result.[110]

Another moisture related physical movement is caused by the growth of biological organisms and higher level flora as discussed in Section 3.4. This is a very prevalent problem at St. Louis Cemetery No. 1, as small cracks formed by the above processes soon become breeding grounds for the aggressive growth of algae and mosses. Cracked roofs also present ready germination sites that collect dirt and seeds deposited by birds, insects and the wind. The growing plants serve to further humidify the micro-environment of the material's surface, keeping the materials damp and inhibiting the de-sorption process.

[110] Handisyde, 36.

Inorganic materials are rarely subject to UV degradation from exposure to strong sunlight. However, movement can occur due to thermal differences by conduction due to the radiant heat from the sun, or convection due to the temperature of the surrounding air. The amount of differential thermal expansion varies widely based on the porosity, formation processes and chemical composition of a material. As an example, Torraca listed the following common material differences:[111]

Approximate unrestrained movement for 30°C change in temperature for materials 1 meter in length

Marble	0.15 mm
Cement Concrete	0.3 to 0.4 mm
Lime-sand mortar	0.3 to 0.4 mm
Common Brick	0.15 to 0.2 mm

Thermal Expansion Coefficients, Unit m/m °C

Concrete	10×10^{-6}
Concrete with exp. Clay	7 to 9×10^{-6}
Cement mortar	10 to 11×10^{-6}
Lime mortar	8 to 10×10^{-6}
Brick	5×10^{-6}

Finally, the few remaining risks to the historic resources at St. Louis Cemetery No. 1 are generally man-driven, rather than moisture driven. These include neglected maintenance, physical impacts through accident or vandalism, theft, mass tourism, cemetery management decisions, local politics and uninformed conservation efforts.[112]

[111] Torraca, 29, 37.
[112] D. Camuffo, "Perspectives on Risks to Architectural Heritage," *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures, Report of the Dahlem Workshop,* Berlin, March 3-8, 1996 N.S. Baer and R. Snethlage, eds. (New York: John Wiley & Sons Ltd., 1997), 76, 80-81.

4.0 CURRENT CONDITIONS

4.1 Analysis of Current Condition Survey Data

Based on the *Survey* made in March, 2001, and field-checked by the Phase 2 team in October, 2001, site conditions were mapped. A series of condition maps are included in Appendix A. Based on the results of the *Survey*, decay mechanisms involving the brick, mortar and stucco were identified for this research.

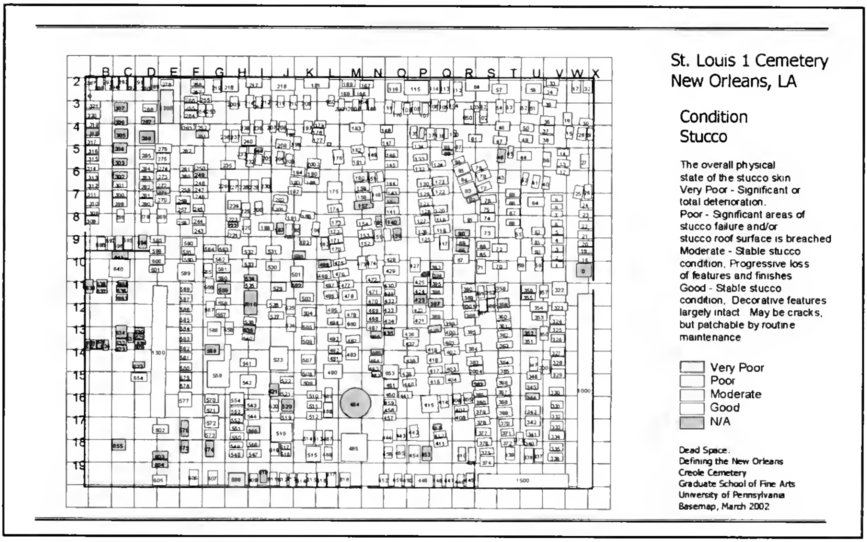


Fig. 4.1 An example of the condition mapping through GIS. See Appendix B for more maps.

4.2 Field Survey Observations

During the course of the *Survey*, the Phase 2 field-check, and this research, five trips were made to the site in March, September, October, and November, 2001, and in March 2002. During the March, 2001, visit, this research had not been contemplated and observations were primarily concentrated on the specific site *Survey*, impacts of tourism and site specific details required for the development of the site survey database design and implementation.[113] The overall personal impression was one of delight and appreciation for a landscape of picturesque decay, then dismay at the discordant pockets of bright white rebuilt tombs and the harsh modern surface materials surrounding so many important historical resources.

During later visits, tomb condition and deterioration results were observed more closely. For a site that has stood for over two centuries, with maintenance mostly neglected during the twentieth century, the tombs have performed well. The signs of deterioration seen in the tombs were not unique, or unexpected. All materials deteriorate. "The combination of building material properties and environmental conditions create the requisite components that perpetuate materials deterioration, hence building failure. … Deterioration is not an exception, nor is it synonymous with

[113] Database designed and programmed for the Studio by J.Peters. "Tourism – A Conservation Tool for St. Louis Cemetery No. 1" unpublished paper co-authored by L. Meyer and J. Peters.

[the designer or builder's] failure."[114] Building structures, whether residential, commercial, or masonry aboveground tombs, will not last forever, and all soon show similar signs of decay unless repainted periodically, maintained, and necessary repairs made with some regularity.

The first sign of decay noticed, as one surveyed the site, was the poor condition of the surface finishes. Many of the surfaces were dirty and heavily covered with biological growth. The historic lime washes have partially worn away with time and had not been reapplied recently. In some cases, modern latex paints have been applied over irregular stucco surfaces containing old paint and lime wash residue, with lack of adhesion evident. Good adhesion occurs either because of mechanical locking of a film into another material, by a strong attraction between the molecules of the two materials, or

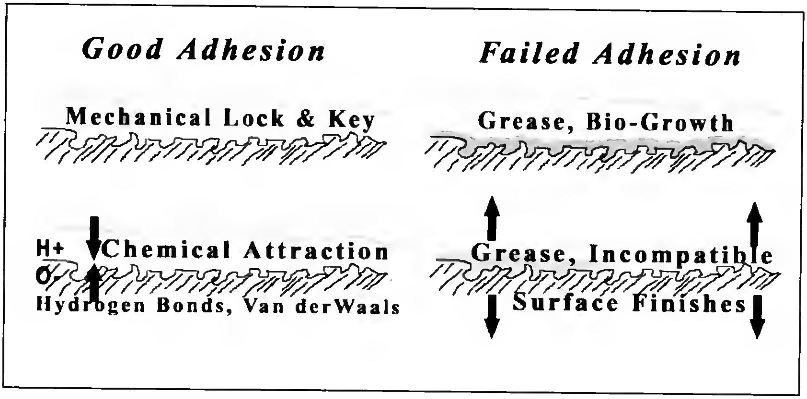


Fig. 4.2 Adhesion mechanisms include both physical and chemical forces.

[114] Harris. 12-14.

by both mechanisms working together. They both depend on surfaces free of grease, clean, and all powdery material and old loosely adherent materials removed so that no planes of weakness are established as the new bonding takes place.[115]

Fig. 4.3 An example of cracked and peeling modern finish..

Based on the *Survey*, of the 617 tombs (not including markers, ruins, or empty spaces), the surface finish on 304 tombs, or 49% were judged to be in the poorest condition with a rating of either a "0" or "1".[116] The survey rated 414 tombs, 67%, as a "0" or "1" for material integrity of the surface finish.[117] The loss of the surface finish is a structure's loss of the first line of defense against the elements and, perhaps more important, is visually very distracting. An otherwise "good" condition tomb would be viewed poorly by most viewers because of this loss of the least expensive, and easiest to fix, part of the building structure system.

[115] Handisyde 41-42.
[116] Based on the *Survey Manual*, a surface finish condition of "0" is defined as "Significant or Total Deterioration: Large-scale surface finish loss and/or failure, exposing stucco or stone beneath." A surface finish condition of "1" is defined as "Poor Condition: Significant areas of finish failure/loss. Unsightly peeling and/or flaking of finish."
[117] Based on the *Survey Manual*, a "0" material integrity is defined as "Total Loss of Integrity: 25% or less of original materials remain or the overwhelming presence of inappropriate replacement materials and/or alterations" and a "1" is defined as "Low Integrity: 26%-50% of original materials remain or the significant presence of inappropriate replacement materials and/or alterations."

The stucco, where visible through missing or failing surface finishes, was generally dry and did not show moisture or salt marks that might be expected from an environment where rising damp is known to be active. However, as Massari and Massari have pointed out, one has to be careful with dampness evaluations and the answer is not always the intuitive one. Efflorescence, an impressive symptom of rising damp, is not always present, but the lack of this symptom does not mean that the structure does not have a serious rising damp problem. It may mean only that there are not significant soluble salts in the water source.[118]

Traces of biological growth covered many tombs and were most prevalent on the bottom third of the tombs and under cornices and other dark areas kept shaded and poorly ventilated. During the *Survey*, 54% of the tombs were marked as showing bio-growth evidence. While the stucco may not have appeared to be damp or showing signs of salt lines, the prevalence of bio-growth and the condition of lost stucco on the lower courses still indicated the presence of moisture problems.

The *Survey* rated only 90 tombs as having a stucco condition as "0" or "1" and only 181 tombs were judged to have poor or total loss of material integrity.[119] These condition definitions were heavily influenced by the amount of stucco actually lost and

[118] Massari and Massari, 2-3.
[119] Based on the Survey Manual, a "0" stucco condition is defined as "Significant Deterioration,: Large-scale stucco loss and/or failure, exposing brick or masonry core." And a "1" condition is "Poor Condition: Significant areas of stucco failure/loss and/or stucco roof surface is breached or compromised by loss and cracking."

did not well capture the different deterioration mechanisms seen throughout the site. The *Survey* did not highly penalize tomb condition on the basis of stucco condition, since stucco was viewed as a sacrificial layer that could be repaired easily or even replaced in a restoration project.

Delamination of the stucco layer was a prevalent problem not documented by the *Survey*. Delamination occurred both between stucco layers and between the stucco and the brick. From afar, the layers often appeared attached, but upon closer inspection, and by rapping the layer lightly, separation was often quite evident. Most of the tombs that showed this condition also had an obvious later application of stucco onto an original or earlier surface, and many of the later stucco layers were of modern cement. The delamination could have occurred because the layer never adhered well to the original stucco, or because the interface between stucco layers or to the brick surface broke over time, due to differences between two incompatible

Fig. 4.4 Delamination and deformation of Stucco

layers or materials. Once delaminated, the outer layer lost its structural support. Gravity and the weight of absorbed moisture caused the layer to move outward, expanding into a bowed condition. Eventually a crack or gap developed, allowing in rainwater, debris and bio-growth.

Where tombs had been patched with cement, the patch edges were often deteriorating, particularly at the interface of historic material and cement patch. On certain tombs, covered by an obvious layer of modern cement, the cement layer had pulled away a layer of brick where the cement was applied directly to the soft brick. Wherever original stucco delaminated from brick, the break was at the stucco to brick interface or within the stucco layer itself.

Cracking was a condition that was surveyed for both the primary structure and roof, although, cracks were more appropriately defined as a stucco condition issue. Cracks in the primary structure were documented for 368 tombs (60%), and in the roof for 333 tombs (54%). There were different patterns of cracks seen at the site based on the deterioration mechanisms at work. Many of the older tombs with unaltered stucco layers had cracks that lined the joints in the brick coursing. In the most serious cases, the brick was actually telescoped out from the tomb wall with the stucco cracked at the brick's edges, but adhered to the brick face. Where these cracks had fully developed, the interior mortar was consistently disintegrated.

Fig. 4.5 Telescoping brick wall.

Fig. 4.6 Open mortar joints and evidence of wetness

A more serious crack situation was seen in many of the original material tombs that were later encased in cement. In these tombs, the high strength of the outer cement stucco held the new casing together in

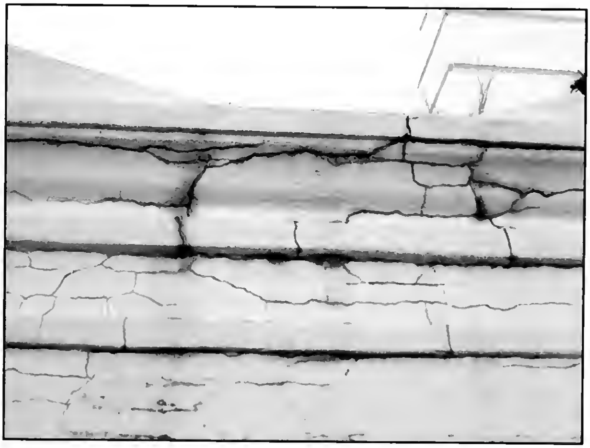


Fig. 4.7 Tomb #518 Sodiedad Cervantes de B.M. Restored in new cement.

compression for a certain time period as the soft permeable inner materials continued to shift according to moisture and temperature driven decay mechanisms. When the pressure became too great, the cement casing fractured, and caused large structural cracks in the structure, as the cement on each side of the crack held on tightly to the soft inner materials and tore them apart as the crack developed. These cracks could happen suddenly. The damage was traumatic to the tomb and could not be easily repaired.

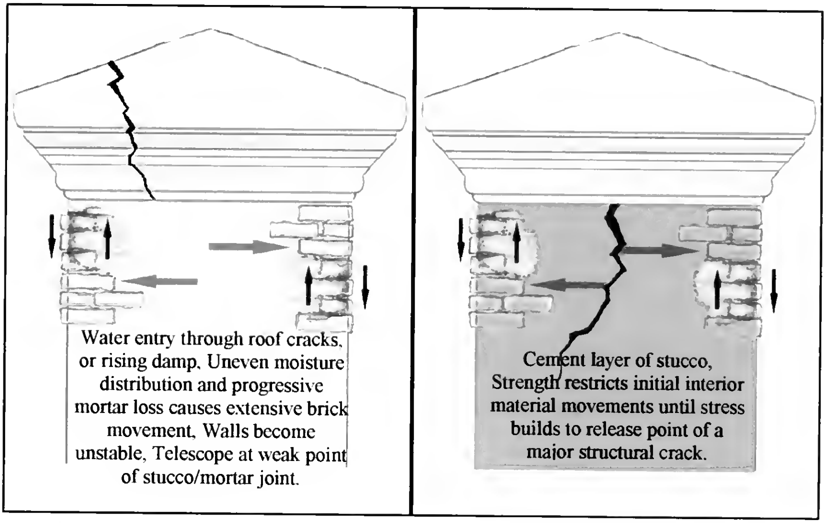


Fig. 4.8 A comparison of damage results seen in walls. Telescoping vs. structural cracking.

The third type of cracking seen at St. Louis Cemetery No. 1 was map cracking. These cracks were evident as a fine network of cracks that do not progress through the stucco layers. One type of map cracking was most often seen in tombs that have a layer of

Fig. 4.9 Salt induced map cracking on cement layer.

hard red or gray lime based surface finish and is a surface finish to stucco interface condition that bears further investigation.

A very different type of map cracking was seen in the gray cement or cement encased tombs, such as the one seen here in Figure 4.9. These cracks started out as fine map cracks, then progressed to larger cracks that could destroy the cement stucco layer. Riccardi, et.al. used optical microscopy to illustrate the expansive needle-like prismatic hexagonal crystals of ettringite.[120] Collepardi has used thermal analysis techniques with SEM imagery to explain the deterioration of restoration cement by the formation of thaumasite and ettringite upon exposure of the cured cement to environmental pollutants. His work helped explain why ettringite formation leads to cracking, spalling, and loss of strength and adhesion in concrete stucco.[121]

[120] M.P. Riccardi et. al., "Thermal, Microscopic and X-Ray Diffraction Studies on Some Ancient Mortars," *Thermochimica Acta* 321 (1998): 207-214.
[121] Mario Collepardi, "Thaumasite Formation and Deterioration in Historic Buildings," *Cement and Concrete Composites* 21 (1999): 147-154.

A number of tombs showed a blistering effect in the stucco, often between layers. This may be due to the presence of unslaked CaO which would continue to hydrate upon exposure to moisture.

Generally the failure of multiple stucco layers is not between the layers of original and new cement stucco. However, where it occurs, the salt decay mechanism, either by cement salts or dissolved calcite drawn to the surface and re-crystallized, is generally the cause.

Three additional problems seen throughout the site are related to design mistakes by the early builders. These problems included flush brick joints, overhanging cornices and unsupported raised flat roofs. Many of the tombs have stucco layers that could be easily pulled away from the brick wall. Over time, the adhesion between the stucco and the brick has broken down. Upon close inspection of these samples, it was found

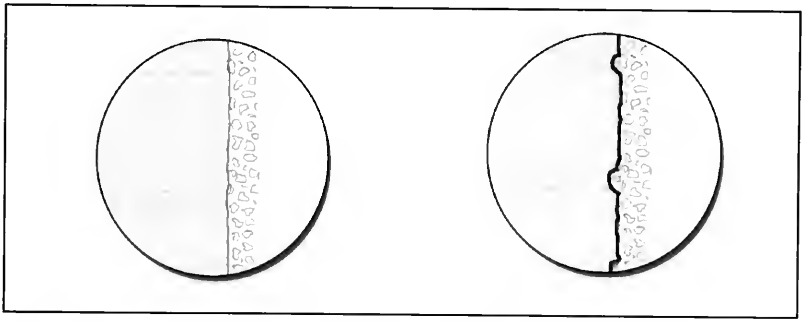


Fig. 4.10 Stucco applied over flush mortar joint vs. recessed "key."

that the mortar joints between the bricks were finished flush with the brick edge, and the stucco, when applied, had no "key" to lock it in place. Had the joints been recessed, the stucco key would have added additional strength to the brick/stucco bond and the adhesion properties would have been much longer lasting, even with the moisture driven decay mechanisms that worked to break down the bond.

Fig. 4.11 Cornice failure.

Many tombs, in otherwise good condition, have cornices with broken corners and exposed brick. Once this vulnerable roof area is exposed, falling rain, dirt, seeds, and bird droppings all can initiate mechanisms that lead to progressive failure of the roof system. As fashions dictated, cornice profiles were extruded more over the tomb. In most cases, the cornices were formed entirely of additional stucco material without extra brick or slate support. After years of gravity pulling moisture laden stucco in a downward direction, the shear stress flanking the corners caused the break pattern seen.


Fig. 4.12 Failed flat roof on a platform tomb.

Some of the raised flat roofs, added most likely as a later addition to "update" the tomb, have no support, beyond the stepped bricks along their edges and a spine down the middle. This large expanse of roof, only partially supported, is under tensile, instead of compressive stress, and neither brick nor stucco has good tensile strength. The stucco cracks, allowing in moisture. Brick displacement from gravity causes more cracking and water entry. Where a stone slab has been added to support the roof, as was often used to support each new tier, the roof remained sound with much less evidence of cracking.

If a tomb had no support under the flat roof, one would conclude that the best roof would be the lightest one possible. Yet in many cases, roofs have been recovered in dense cement. In some cases, very heavy preformed concrete roofs have been placed on the tomb, setting up even greater downward pressure on the tomb top and walls, adding more stress to the entire system, including the marble tablet in the vault opening, and will most likely cause accelerated sinking and eccentric settlement. These new "additions" also completely obliterate the historic materials and cornice profiles and style evidence.

There are many conditions of deterioration seen in the marble tablet systems and metalwork. As they are not the subject of this research, such materials will not be discussed, except where the system impacts the stucco and masonry. The marble surrounds on many of the tombs were often sealed to the stucco with incompatible mortars or modern adhesives, such as epoxies. When these seals broke, a vertical channel for moisture, dirt and seeds was created. The metalwork connection into the side of the tomb is also a weak point and many connections show cracked stucco around the metal. With corrosion expanding the metal, the stucco to metal seal easily breaks, compromising the stucco layer.

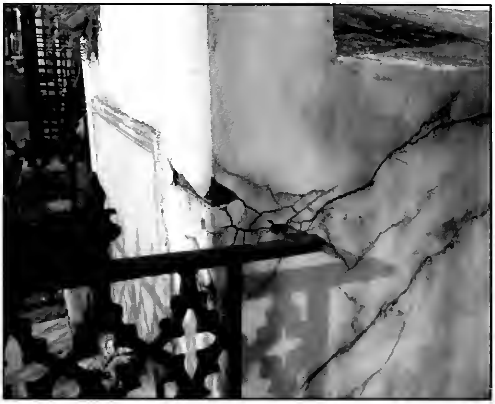


Fig. 4.13 Tomb #14, Cracking at the interface of stucco and metal connection.

Since there are so many tombs at St. Louis Cemetery No. 1 with exposed brick, the brick condition can be observed quite easily. There are a variety of brick types, colors and sizes. Often, multiple brick types and sizes can be found in the same tomb. All bricks observed at the site appear to be handmade, even those from the few tombs that appear to be of a harder, imported brick. The local river "reds", and the lake "tans"

were both soft, with the river bricks being the softest. These bricks were not intended to be exposed and needed the protective covering of the stucco. When the stucco was intact, the bricks beneath showed very little deterioration and the mortar in the joints did not appear to be damaged to any great extent. However, for those tombs where the brick and mortar were exposed, the mortar joints suffered severe loss and the faces and edges of the bricks also showed erosion. This was most obvious at the corners of the tombs.

Once the mortar joints break down, the bricks become loose, and shifting of bricks occur easily as moisture moves through the structure, through thermal expansion, or from mechanical stresses, such as the addition of a heavy new roof, as mentioned above. However, in most cases, the load bearing brick walls are quite resilient. This might be due partly to the fact that as the mortar breaks down, another decay mechanism takes place as dirt and flora took residence, actually providing needed support to the damaged joint.

Although these exposed brick tombs appear to be in terrible condition, the trained conservator can see a relatively standard project. After consulting archival images to better inform the work, lost bricks need to be replaced, the roof bricks often need resetting, new bedding and pointing mortar are needed throughout and the stucco and surface finishes must be repaired or replaced. With these remedies, even the worst looking tombs can be restored without significant loss of historic fabric.

Fig. 4.14
Tomb #351
"Before"

Tomb 4.15
Tomb #351
"After"

5.0 Material Analysis and Characterization

A testing and analysis program was designed to document and characterize the construction materials in the aboveground tombs at St. Louis Cemetery No. 1. The field assessment of deterioration patterns had documented that structural integrity of tombs was rarely compromised as long as the outer skin of protective stucco was intact. Therefore, the test design emphasized stucco and stucco on brick analysis, and samples from over 10% of the tomb inventory, well distributed through the site were required.

Through a review of the literature, many mortar and stucco analysis research studies were identified. While the research objectives varied, there was a general consistency in methodology. Whether the article was published in conservation journals, journals on analytical test equipment or cement chemistry publications, the research work started with documentation and visual inspection and proceeded to methods of separation, gravimetric analysis, chemical analysis, optical microscopy and physical response to moisture. Advanced analytical tools used most often were XRD (powder X-Ray diffraction) and SEM (Scanning Electron Microscopy). Many of the projects published were featured in multiple journals and the later phase of their work focused on TGA-DTA (thermal gravimetric analysis, differential thermal analysis) and other specialized techniques used to answer their particular research objectives.

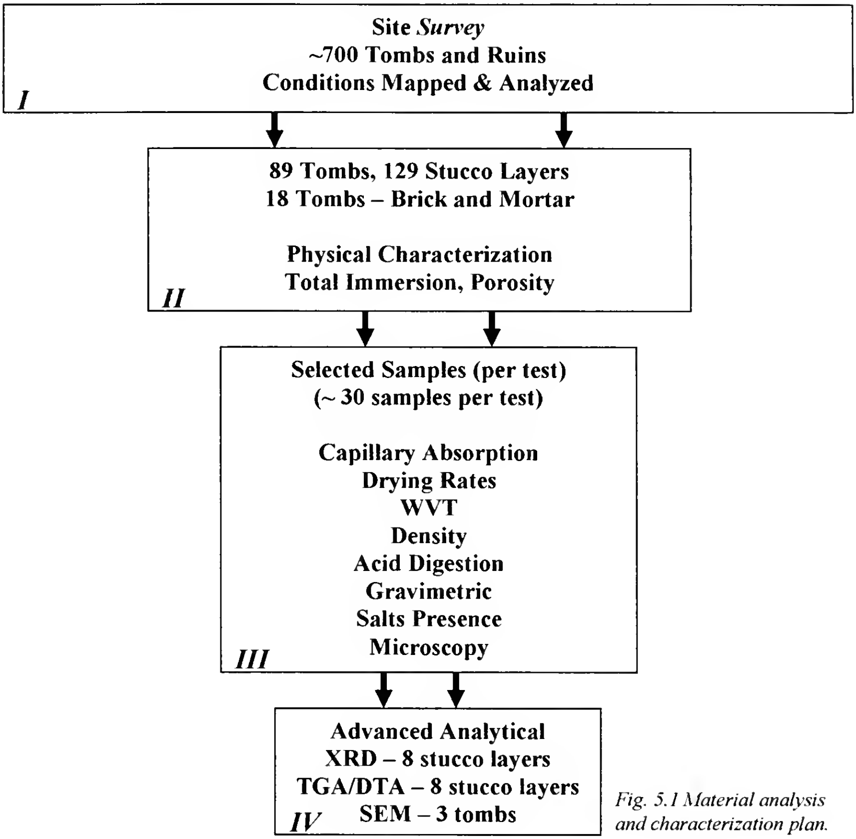


Fig. 5.1 Material analysis and characterization plan.

This research followed a similar testing plan, starting with physical characterization of brick, mortar and stucco. As moisture related movement and reactions were hypothesized to be the primary factors in deterioration, the results from water absorption by total immersion were used with the characteristic of gross sample color to separate the large sample set into groups. For a smaller subset of samples, capillary

absorption and drying rates were studied and gravimetric analysis and micro-structure were used for documentation. Specific stucco binder components were confirmed with SEM, XRD and TGA/DTA.

5.1 Sampling Strategies

Since St. Louis Cemetery No. 1 is still an active burial site and the tombs are owned by families, the sampling program was limited to tombs that were in very advanced states of deterioration. During sampling visits to the site, a total of 89 tombs were sampled for 129 stucco layers, and 18 tombs were also sampled for brick and mortar. No tombs were damaged in retrieving these samples. In each case, the stucco was already delaminating from the brickwork, or was attached to brickwork that was loose in a badly deteriorated tomb. The bricks were exposed and loose. Even with this limitation on sampling, a good distribution of the site, tomb type and stucco and brick type was achieved. Documentation and photographs of the sample locations contributed to the final analysis of decay mechanisms. GIS maps indicating those tombs sampled and their conditions can be viewed in Appendix A.

5.1.1 Brick

Using the *Survey* completed in March, 2001, and field checked in October, 2001, tombs that had a primary structure condition of "0" (Significant or Total Deterioration) or "1" (Poor Condition) were inspected as candidates for brick sampling. Most of the poorest condition tombs with available loose bricks were platform, parapet and step tombs and a majority of the samples came from those tomb types, with the exception of the brick samples from the 1200 wall vault east and middle sections. Where there was more than one type of brick evident in a tomb, each was sampled to analyze the differences.

Although the original plan was to take core samples from several tombs, it was decided, during the sampling trip, that coring for samples could be too damaging to the tombs. In a future research project, coring can be attempted when a tomb is selected for an active restoration project. At that time, it would also be instructive to install environmental probes within the tomb and within the structural system components, to monitor temperature and moisture over time.

To obtain an estimate of the moisture vapor transmission of the tomb wall system, bricks of several tombs were chosen where the complete system of brick, stucco layers and surface finish were intact. During the *Survey* in March, 2001, and again in this

research, attempts were made to retrieve bricks from the site and transport them to the lab fully sealed so that valid measurements could be made of the moisture content *in-situ*. However, the packaging material did not hold up through transport and several bricks arrived broken and the sealed bags were punctured. In the future, *in-situ* moisture content measurement will be best achieved by using a battery operated balance on site.

5.1.2 Stucco / Surface Finish Assembly

The *Survey* was also used to identify dated tombs where the stucco condition was "0" (significant or total deterioration) or "1" (poor condition). During the sampling trips, additional tombs were sampled due to unique conditions, color or where spots of stucco deterioration made the taking of a sample possible on a tomb where the stucco condition had been rated higher than a "1". For most tombs, less than 50 grams were sampled. For those tombs identified for gravimetric analysis and water vapor transmission (WVT) testing, approximately 150 gram samples were taken so that a full 5.3 mm disc could be prepared for the WVT test. Where there were multiple layers of stucco, as in an original stucco layer covered by a later cement layer, samples of both layers were taken.

5.1.3 Mortar

In each tomb where brick samples were taken, mortar samples were also taken. An attempt was made to retrieve unexposed interior samples that had not broken down due to weathering, water absorption and/or biological growth.

5.2 Laboratory Analysis

5.2.1 Visual Inspection and Physical Characterization

Visual inspection and physical characterization are the most basic of the analytical techniques. It is important to capture contextual information about the sample, such as where it was located on the structure, the condition of the structure or region from which the sample was taken, damage levels and locations (delamination, disaggregation, cracking, etc.) general surface appearance, and contamination information. For this research, a report of the target tombs was created from the database to use in the field during sample collection to collect information quickly and accurately. Comments and planned tests were marked and sample locations could often be indicated on the photograph. (See Appendix B – Sampling Record for an example of the field comments.)

After collection, stucco samples were brushed clean with a wire brush and all loose surface finish removed. Where possible, any remaining surface finish was removed with a dental pick, scalpel and/or coarse grit sandpaper. Where samples contained more than one layer of stucco, all attempts were made to separate the layers and test each separately for moisture response, for comparison to the intact multi-layer system. Samples were coded as to the layer color(s) and whether surface finish was still a part of the sample. Small samples were taken of selected stucco layers and surface finishes for later microscopy work.

Based on gross color and texture, the samples were subjectively typed into 6 groups:

1. White Group – appeared to be the oldest, mostly crushed shell based lime
2. Tan Group – light sandy color, very porous
3. Dark Tan Group – darker, caramel type tan, denser
4. Gray Group – more recent layers of cement based stucco
5. Combination Tan/Gray Group – multiple layers
6. Combination Dark Tan/Gray Group – multiple layers

A later subset of White Gray Group was designated, as this type of cement layer seemed to have very different properties from the Gray Group. The broken interior of each sample was further characterized by Munsell Soil Charts (ASTM D1535-97), and aggregate shape and size were characterized. For those samples that were to be analyzed by acid digestion and gravimetrically, the surface texture was evaluated

further by comparison to commercial sandpaper grit sizes and sample hardness was given a Mohs hardness scale number by using a fingernail, a scalpel and a glass slide. The Mohs hardness scale orders 10 common minerals by hardness, numbered 1 to 10. One's fingernail has a hardness of about 2.5, between the hardness of gypsum and calcite; a jackknife blade is estimated at 5.5, between apatite and feldspar; and a plate glass is about 6, or the hardness of feldspar. A 0 to 3 scale was used to rate grinding difficulty and resistance to break, to further characterize hardness. See Appendix C – Experimental Data for a summary of the stucco characterization.

The bedding mortar samples were brushed lightly to remove loose fragments and evidence of biological growth. Samples were color typed with the Munsell Soil Charts (ASTM D1535-97), and assessed for hardness using the 0 to 3 scale of grinding difficulty and resistance to break, as described above. See Appendix C – Experimental Data for a summary of the mortar characterization.

The brick samples were scrubbed lightly to clean off dirt and biological growth, then weighed and measured in the length, depth and height dimensions. An additional 41 measurements were made on bricks still intact in tombs during the March, 2002, field trip to St. Louis Cemetery No. 1, and were added to the analysis of brick sizes.

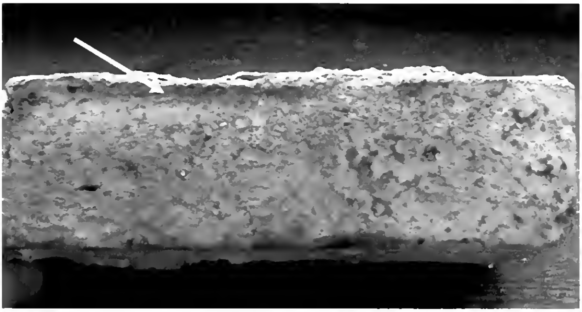
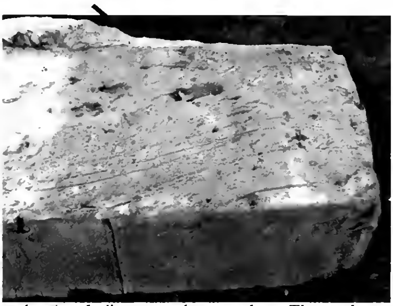
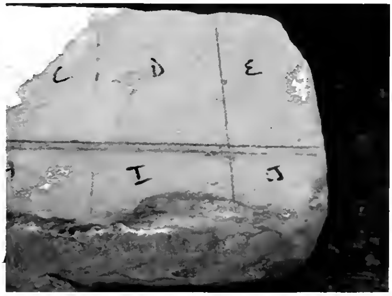


Fig. 5.2 A hand made brick evidenced by the lip formed when brick was removed from its mold before being fully dry.

Using the reference by Gurcke, *Bricks and Brickmaking: A Handbook for Historical Archaeology*, the sampled bricks were characterized by color and texture, the marks on the struck face, the evidence of lips formed on the edges, and any additional marks showing that the bricks were sand or water struck.[122] Each brick was marked for cutting and cut with a water cooled Plasplug Diamond Wheel Tile Cutter into 6 or more pieces (~2.5" x 3.5" x 1.5") for further tests.



the "strike" across the wet clay. The strike was usually a straight edge of wood



[122] Karl Gurcke, *Bricks and Brickmaking: A Handbook for Historical Archaeology*. (Moscow, ID: University of Idaho Press, 1987).

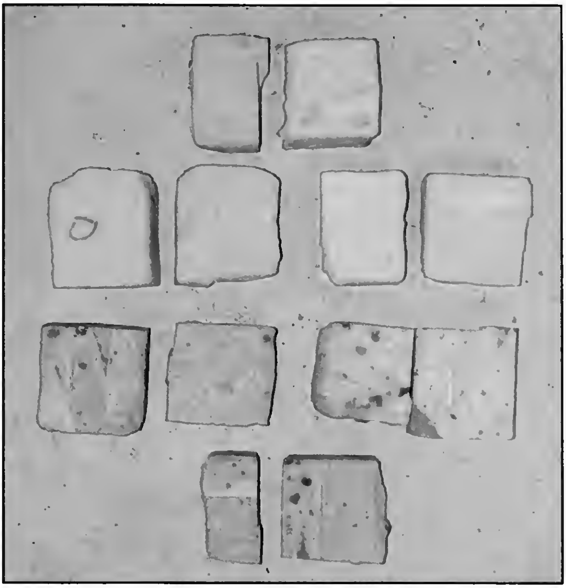


Fig. 5.5 Examples of brick samples. The top six samples are River brick which tend to be red to reddish orange. The bottom six samples are Lake brick, which are tan to pink and usually have spots of burnt impurities.

5.2.2 Moisture Absorption by Total Immersion

Fig. 5.6 Samples of stucco during total immersion test.

Testing methodology for moisture absorption by total immersion was adapted from several sources.[123] For the stucco samples, a target size of 3.5 cm x 3.5 cm and desired weight of 20 grams was selected. Due to the small quantity of many of the samples, weights ranged from a low of 3.9 g to a high of 30.5 g. The average dry weight was 12.7 g. Each sample of stucco was placed in an individually weighed aluminum pan and 15 small sample pans were placed in a large disposable aluminum tray. The 119 samples were divided into 8 trays of 13-16 samples each, so that each test series allowed enough time for all samples to be weighed before the next timed weighing cycle was scheduled. Each tray of samples was air-dried at 68-70° F and 30-35% RH. The samples were then dried for 12 or more hours at 83 °C, until sample weights between weighings were constant within ±0.1%.

[123] ASTM C97-83 Standard Test Methods for Absorption and Bulk-Specific Gravity of Dimension Stone; Jeanne Marie Teutonico, "Water Absorption by Total Immersion," *A Laboratory Manual for Architectural Conservators*, (Rome: ICCROM, 1988), 35; NORMAL 7/81, Draft Translation by E. Charola; Ernesto Borrelli, *Porosity: ARC Laboratory Handbook* Volume 2/99, (Rome: ICCROM, 1999), 10.

The dry weight, M_0, of each sample was recorded and distilled water was added to fill each pan, totally submerging the stucco sample. The samples were removed from the water, blotted dry and weighed on an Ohaus Scout II scale with ± 0.1 g error at given intervals until the difference between two successive weighings at a 24 hour interval was less than 1% of the dry weight, and less than 0.1% of the total moisture absorption. At the end of the immersion time, the final saturated weight, M_{SAT}, was recorded. The percent of moisture absorbed by total immersion at atmospheric pressure, also called the Imbibition Capacity, was calculated:

$$IC = (M_{SAT} - M_0) / M_0 \times 100$$

The mass of the pores, M_p, was calculated:

$$M_p = M_{SAT} - M_0$$

Since the density of water is 1 g/cm^3 at 24 °C, the mass of the pores, M_p can be considered to be the open pore volume, V_p. Each sample was then placed in a small beaker filled with 60 ml of distilled water. The amount of water displaced, or the apparent volume V_a, was used to estimate the percent open porosity of each stucco sample.

$$\% \text{ Open Porosity} = \% \text{ Voids} = V_p/V_a \times 100$$

To obtain an estimate of the water absorption coefficient, or the rate at which the samples would have absorbed through capillary action, the slope of the initial section of the absorption curve was calculated.

The samples were then dried at 83°C until they reached constant weight and re-weighed. The first 106 samples were then tested for surface absorption by dropping 1 ml drop of de-ionized water onto the surface and measuring the time required for the drop to be fully absorbed. The results were very erratic, depending on where the drop was placed on the irregular stucco surfaces, and were not used for analysis.

The wet and dry condition of each sample was photographed and any discoloration of water or disaggregation of sample was recorded. The % Moisture Absorption, % Porosity, and initial slope results for all samples and sample comments are presented in Appendix C – Experimental Data.

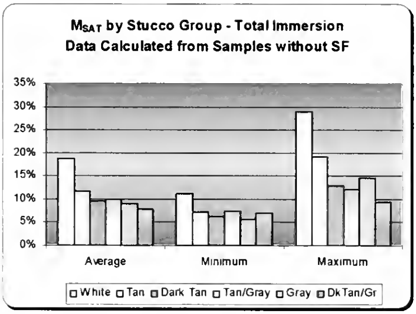


Fig. 5.7 Total saturation point average, minimum and maximum by group.

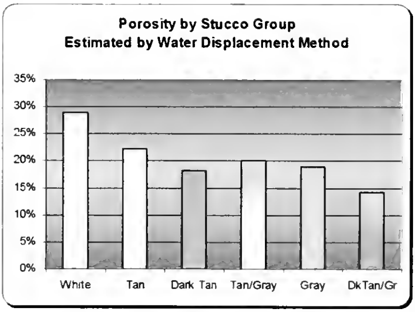


Fig. 5.8 Average open porosity by group.

This large set of samples included a mixture of single stucco layers, multiple layers and samples with surface finish caught between layers. Even with the many sample irregularities, the moisture response of the White stucco samples was the greatest at almost 2 times the response of the least absorbent Gray group. The graphs above show the

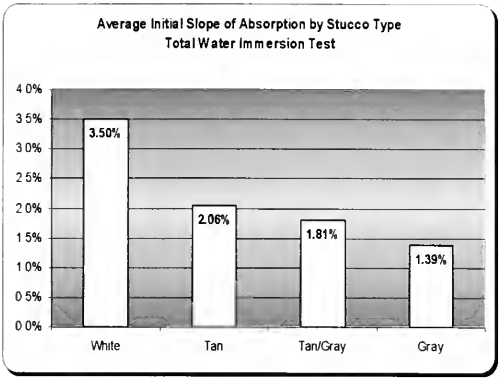


Fig. 5.9 Average initial slope of absorption by group.

average percent of moisture gained in the fully saturated condition of those samples without surface finishes. The Gray samples averaged a similar porosity to the Dark Tan group, showing that porosity alone does not dictate absorbing capacity.

The water absorption by total immersion test provides an indication of the total amount of moisture that a material can hold. Figure 5.9 shows the initial slope of the curve of M_t vs. time. It clearly shows differences in the initial capillary absorption properties, or the suction power, between materials. In the case of the 4 stucco color groups, the differences followed the pattern seen in the imbibition capacity results. The White group averaged 2.5 times the absorption of the Gray group.

Most of the mortar samples were less than 20 g, so the largest piece available was chosen. In several cases, two small mortar samples were used for the test. The average dry weight of the mortar samples tested was 17.6 g. Each sample of mortar was placed in an individually weighed aluminum pan and the 15 small sample pans were placed in

a large disposable aluminum tray. The tray of samples was air-dried at 68-70°F and between 30-35% RH. The samples were then dried for over 12 hours at 83°C.

The dry weight of each sample was recorded and distilled water was added to fill each pan, totally submerging the sample. The samples were removed from the water, blotted dry and weighed on an Ohaus Scout II scale with ± 0.1 g error at the times used for the stucco total immersion test. The 6 day cycle that had fully saturated the stucco samples was not long enough for the mortar samples, which took 8 days to reach constant weight saturation. At the end of the immersion time, the final saturated weight, M_{SAT}, was recorded. The samples that were not too soft for handling were tested for open porosity. The samples were dried to constant weight and re-weighed. The final dry weight was used for all calculations, as many of the mortar samples experienced disintegration during the immersion in water. The percent of moisture absorbed by total immersion, percent open porosity and the initial slope were calculated by the equations given above. See Appendix C – Experimental Data.

An interesting comparison can be made between the M_{SAT} of the interior mortar sample and the M_{SAT} of the first layer of stucco, the layer that would normally interface with the mortar. In all cases, the stucco layer was less capable of holding moisture than the mortar. This difference in moisture capacity has the potential to be a positive aid in the drying out of interior moisture, assuming the stucco layer's ability to draw moisture by

capillary action is great enough, a property that was discussed in Section 3.5 on moisture driven decay mechanisms. The mortar samples were generally much more delicate and more easily dissolved than the stucco samples, indicating that the mortar would be easily damaged in a water filled joint.

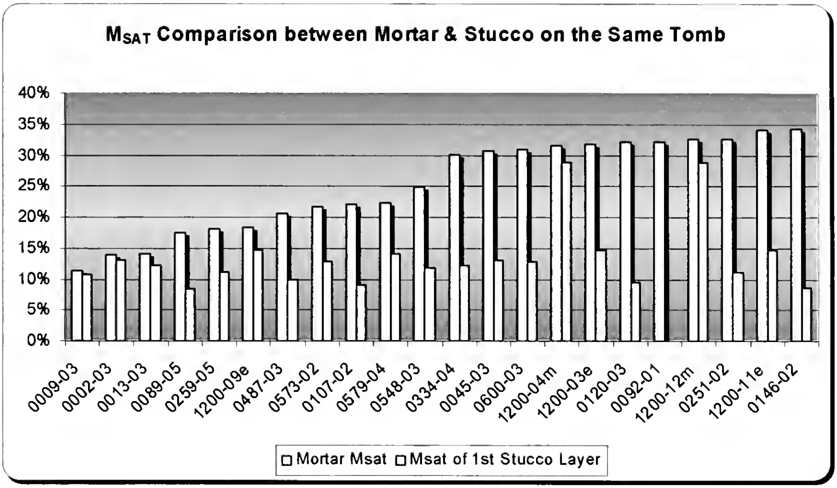


Fig. 5.10 Comparison of the total saturation point for mortar and stucco of the same tomb.

For the total immersion tests on the brick samples, each was cut into pieces and 3 samples per brick, each less than 250 g, were chosen for the test. The brick samples were air dried at 68-70° F and between 30-35% RH for 3 days. The 3 samples of each brick were then placed in a disposable aluminum dish and dried at 83°C for 14

or more hours. The 21 sample sets were tested in 3 batches to allow working and weighing time between samples. The batches were staggered by several days.

Fig. 5.11 Total immersion test on brick.

The dry weight of each brick sample was recorded and distilled water was added to fill each dish, totally submerging the 3 brick samples. The samples were removed from the water, blotted dry and weighed at given intervals until the difference between two successive weighings at a 24 hour interval was less than 1% of the dry weight, and less than 0.1% of the total moisture absorption. The cycle took 16 days. All weights were made with an ACB 300 scale with ± 0.01 g error. At the end of the immersion time of 16 days, the final weight, M_{SAT} was recorded. The mass of the pores was calculated by the equations given above and the % open porosity was estimated by the amount of water displaced when the sample was placed in a large beaker filled with 550 or 700 m of distilled water, depending on the sample size.

An assessment was made of the sediment dissolved from the brick during immersion. A disintegration dating scale was used with a rating of "1 = Minimal amount of dissolving clays" to "5 = Large amount of dissolving clays." For each brick, the 3

sample weights, M_{SAT}, % water absorption, and % open porosity were averaged and the results are presented in Appendix C – Experimental Data.

5.2.3 Additional Tests on Intact Bricks

Before the intact bricks were cut up for the total immersion testing described above, several were tested for surface water permeability through the use of RILEM induction tubes.[124] Both types of RILEM tubes were tried. The tube designed for testing of vertical surfaces simulates the action of wind-driven rain. The one designed for horizontal surfaces simulates ground water rising through the base, or falling water on the structure top or other exposed surfaces.

During the *Survey* in March, 2001, this test was attempted on several tombs with the bricks *in situ*. It was not successful as the water absorbed too quickly to measure, or the seals would not hold. It was thought that the test could be more successful on sample bricks under controlled laboratory conditions. Several brick samples were chosen and scrubbed clean of loose dirt and biological growth. Sealant putty was warmed slightly, rolled into a thick strand and applied to the RILEM tube. The tube was then adhered to the brick surface in the horizontal or vertical mode, depending on

[124] Gale, Frances. "Measurement of Water Absorption." *APT Bulletin* Vol. 21 No. 3-4, (1989): 8-9; RILEM International Symposium on the Deterioration and Protection of Stone Monuments: Experimental Methods (Test No. II.4).

the test, in a location that was free of stucco or mortar remnants. De-ionized water was added to the tube and an attempt was made to measure the water absorbed by the brick. In all cases, the results were too erratic to use, with no test repetition yielding consistent results. Generally, on the soft river bricks, 5 ml of water was absorbed within a minute. The harder lake bricks took about 2 -3 minutes to absorb the 5 ml of water. In addition, attempts were made to test the stucco covered brick areas. However, the seal would not hold on the rough surfaces. It was concluded that this test would not be useful for characterizing the bricks in this research.

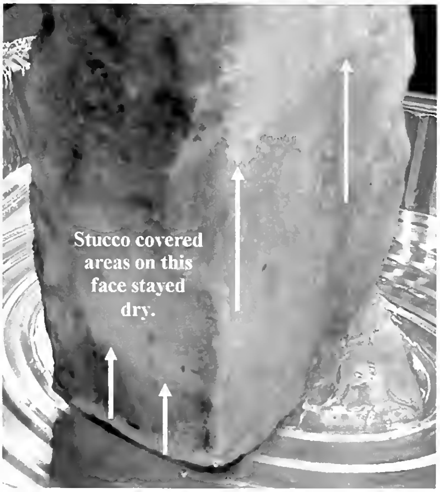


Fig. 5.12 Capillary rise attempt on a full brick.. The brick wet out beneath the stucco. The stucco remained dry.

An attempt was made to test the capillary rise rates on the individual bricks.[125] Several brick samples were chosen and scrubbed clean of loose dirt and biological growth. The selected bricks were stood on end on glass rods in a container and de-ionized water was added to a level of 1 cm above the brick edge. Measurements were taken on each of the brick faces every minute for

[125] NORMAL 11/85 Capillary Water Absorption and Capillary Absorption Coefficient; RILEM International Symposium on the Deterioration and Protection of Stone Monuments: Experimental Methods (Test No. II.4).

the first 5 minutes, every 5 minutes until 30 minutes had passed, and then every 30 minutes until the brick was fully wet. These results were also assessed to be erratic, but illustrative of the manner in which bricks can completely wet out beneath a seemingly dry stucco layer. Only 6 bricks were tried and it was decided that this test method also was not useful for these materials.

5.2.4 Development of Test Plan for Further Analysis

The physical characterization and total immersion water absorption tests were selected as the means to develop data that would allow for the classification of such a large sample universe into groups that merited further testing. The tests described in the following sections were not run on all samples. Representative samples were chosen to determine the properties of the individual stucco and brick types, and to show the combined impacts of stucco on brick, the differing stucco layers upon each other, and stucco with surface finishes. Many of the tombs chosen for analysis included the 18 for which the full system of stucco, brick and mortar were available. For the remainder of the samples required, an important criterion was the availability of large enough samples to yield both the 5.3 mm disc needed for the MVT test and at least 20 g for the acid digestion and gravimetric analysis. Finally, 3 tombs, #09, #600 and #1200, that clearly illustrated material incompatibilities both in the field and in the initial testing phase, were chosen for advanced analytical work, including Thin-Section Polarized

Light Microscopy, X-Ray Diffraction, Scanning Electron Microscopy and Differential Thermal Analysis. The full sampling plan can be reviewed in Appendix C.

5.2.5 Water Vapor Transmission

The moisture or water vapor transmission rate (MVT or WVT), is a property of a material that is useful in evaluating its permeability to moisture vapor. It is defined by ASTM as "the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface."[126] A high WVT allows a material to adjust more rapidly, when adhered to a damper material, such as the situation in St. Louis Cemetery No. 1, where the interior bricks can become wet from rising damp. Field inspection has verified that the stucco layers are often dry over damp bricks, and the ability of the stucco to transmit moisture vapor was thought to aid in the elimination of the interior dampness.

Stucco – The Water Method of ASTM E 96-95 was adapted for use in this research. Due to the availability of samples, only one sample for each tomb condition was prepared instead of the 3 specified in the test method. The samples were somewhat irregular and care was taken to cut the sample from the most uniformly thick section of

[126] ASTM E 96-95 Standard Test Methods for Water Vapor Transmission of Materials; Judith Jacob and Norman R. Weiss. "Water Vapor Transmission: Mortars and Paint" *APT Bulletin* Vol. XXI No. 3&4 (1989): 62-70; NORMAL 21/85; ASTM definitions are found in Terminology C 168.

the material. Representative samples were chosen from each of the stucco color groups and an attempt was made to create several comparison pairs showing the same stucco with and without surface finish. For Tombs #09, #200 and #600, tombs for which the most analytical testing was conducted, samples of the gray stucco layered over the original stucco were tested against one of the separated layers.

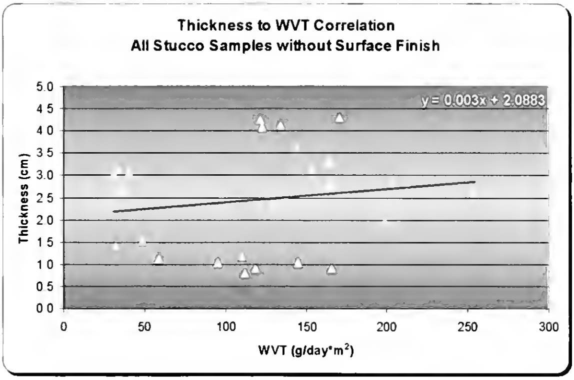


Fig. 5.13 Thickness to WVT correlation.

The samples differed widely in thickness. However, it was determined that thickness differences would not invalidate the test once the samples reached equilibrium in the test chamber. The WVT values were calculated for a 7 day period after the samples reached equilibrium after at least 10 days. The final WVT results showed a positive correlation with sample thickness, with the thicker samples having a greater ability to transmit water vapor. This correlation indicated that the differences were due to the stucco type, not thickness. Had the thickness differences caused WVT to decline with increasing thickness, the samples would have required further cutting to ensure that all samples were of similar thickness.

Polyethylene beakers (100ml) with a 5.5 cm top opening and a 2 cm ledge were chosen for the test containers. Stucco discs were cut to 5.1-5.4 cm diameter. The discs were dried at 83°C for 12 hours, then cooled in a desiccator and weighed. During this time, the 10 gallon fish tank to be used as the desiccator was outfitted with wire shelves, and trays of anhydrous calcium sulfate (DRIERITE®). The tank was sealed with wide impermeable transparent tape to bring the interior to dry conditions before the start of the test. A combination thermometer and hygrometer was placed in the tank for temperature and humidity readings. The dried samples were wrapped tightly with electrical tape. The beakers were labeled and filled with 60 ml of distilled water, which brought the water level to within ¾ ± ¼ in of the bottom of the sample.

Fig. 5.14 Stucco sample preparation for WVT test.

Each sample was placed in its marked beaker and melted paraffin wax was applied around the edge with an eyedropper to seal the assembly. The full test chamber of sample, tape, paraffin wax, beaker and water was weighed. The samples were placed in the

tank on elevated wire shelves over the trays of anhydrous calcium sulfate desiccant. The samples were spaced to allow good airflow between all samples. The top of the tank was sealed with wide impermeable tape.

Brick – The Water Method of ASTM E 96-95 was adapted for use in this research. Due to the minimal availability of samples, only one sample for each tomb condition was prepared instead of the 3 specified in the test method. Brick cubes were cut with a diamond edge, water cooled saw to approximately 1.9 cm by 3.5 cm by 3.5 cm. This allowed the brick cubes to inset into the polyethylene beaker and allow a plastic shield to rest on the brick braced by the beaker top's ledge. Representative samples were cut from each of the sampled bricks and, where possible, separate samples were prepared to compare the bare brick to the same brick with the adhered layer of stucco.

Polyethylene beakers (100ml) with a 5.5 cm top opening and a 2 cm ledge were chosen as the test containers. Polyethylene discs were cut to 5.4 cm diameter and a window of approximately 2.4 cm by 2.4 cm was cut to expose the brick surface. The brick samples were dried at 83°C for 12 hours, then cooled in a desiccator and weighed. During this time, the 10 gallon tank to be used was prepared as described above for the stucco samples.

The dried samples were wrapped tightly with electrical tape. The beakers were labeled and filled with 50 ml of distilled water which brought the water level to within ¾ ± ¼ in of the bottom of the sample. Each sample was placed in its marked beaker, the plastic shield was placed on top of the sample and melted paraffin wax was applied around the edge of the shield and within the exposure window with an eyedropper to seal the assembly. The measurements of the exposed window were taken so that the exposure area could be calculated. The full test chamber of sample, tape, paraffin wax, beaker and water was weighed. The samples were placed in the 10 gallon fish tank on elevated wire shelves over the trays of anhydrous calcium sulfate desiccant. The samples were spaced to allow good airflow between all samples. The top of the tank was sealed.

Fig. 5.15 Brick cubes for WVT test.

WVT Calculations - The stucco and brick samples were run in two separate batches in early March, 2002, and then after new samples were obtained in early April, 2002. For the first run, the weights of the total assemblies were taken every 24 hours. A 7-day period after the 10^{th} day was chosen for calculations, after it was assured that all

samples were at an equilibrium rate of moisture transmission. For the second run, the weights were taken less frequently, and a 7-day period was also chosen after the samples had been exposed for 10 days. For both runs, the samples stayed in the tanks for over 18 days. Any sample that tipped over, broke the seal or cracked was eliminated. The tank conditions were kept at between 69-71°C and 22-30% RH. All weights were made with an ACB 300 balance with a ±0.01 g error. Readings of weight change rates were very consistent during the testing cycle as can be seen in the curves of daily weight loss % of all the brick samples in Figure 5.16 below.

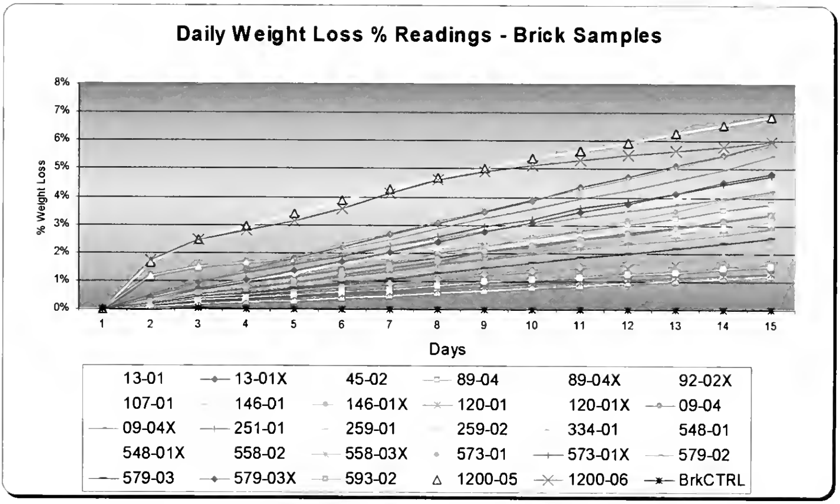


Fig. 5.16 15 daily weight loss % readings – Brick samples.

The water vapor transmission (WVT) is calculated as follows:

$$WVT = \frac{G}{tA}$$

Where G = weight change (grams)
t = time (hours)
A = test area (cm^2)
WVT = rate of water vapor transmission, g/(h cm^2)

Calculations were also made for g/day m^2. See Appendix C for a summary chart of the experimental results.

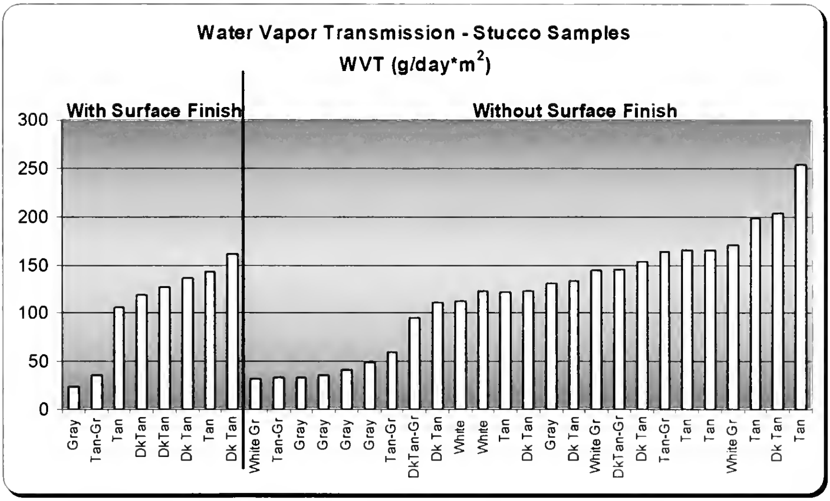


Fig 5.17 Water vapor transmission results for stucco samples.

Generally, the stucco samples with surface finish (modern) were higher in WVT than had been expected, but were still consistently lower than the same or similar sample tested without surface finish. In the sample of Tomb #548 tested with and without a

modern surface finish, the modern finish reduced the WVT of the stucco by almost 40%. Yet in Tomb #89, where the Dark Tan stucco is still covered with thick remnants of a permeable lime based surface finish, the difference between WVT results was insignificant, or within experimental error.

Table 2

Water Vapor Transmission Results for Specific Stucco Samples Tested With and Without Surface Finish (SF)

Samples	Type	Finish	Wt. Change (g)	Thickness (cm)	Test Area (cm)	Diameter (cm)	WVT $g/day*m^2$
548-02	Tan	Mod SF	1.64	0.790	22.05	5.2	106
548-04X	Tan	No SF	2.45	2.780	21.23	5.2	165
89-02	Dk Tan	Lime SF	1.95	0.709	20.42	5.1	136
89-X	Dk Tan	No SF	1.99	4.130	21.23	5.2	134

The averages for the non-SF samples, when separated into color groups and by the different brick types, clearly showed the Gray (cement) Group stucco to have the lowest WVT and the very soft, porous River brick to have the highest WVT. According to these results, in a 2.5 by 3 meter wall of lake brick covered by Gray stucco, the stucco would only allow 435 g of the 4.5 kg of moisture vapor that the lake brick could pass.

Figure 5.18 shows the progression of WVT results from the least permeable to the most. A layer of Tan stucco is 3 times more capable of passing moisture vapor than a layer of Gray stucco. All of the brick with stucco samples had either Tan or Dark Tan stucco. The bare bricks are the most permeable and when covered with stucco, they loose approximately half their ability to pass moisture vapor.

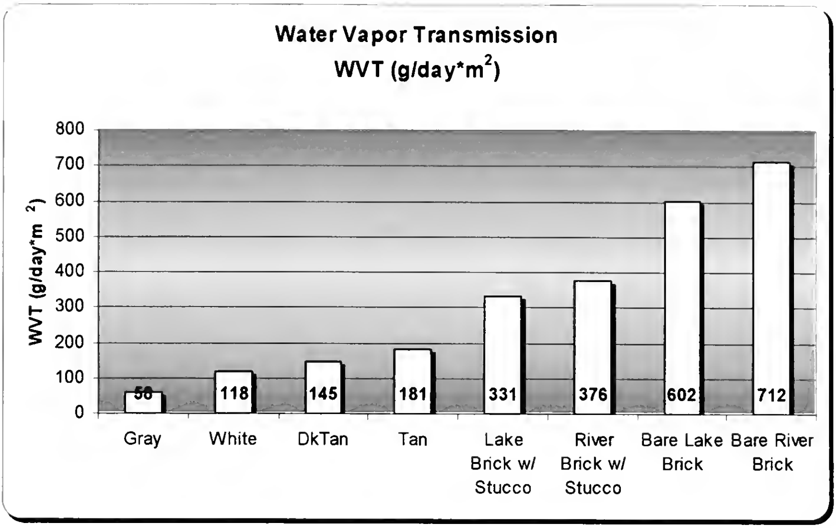


Fig. 5.18 Water vapor transmission results for brick samples.

5.2.6 Capillary Absorption

The methodology for capillary absorption and drying rates was adapted from the NORMAL and RILEM published test methods, the work of Massari and Massari and Vos, and the laboratory developed by E. Charola.[127] After the conclusion of the MVT test, the 35 stucco discs and 31 brick cubes were dried for 24 hours at 83 °C and weighed on the ACB 300 scale to ±0.01g. The stucco discs were set on edge in open wire baskets adapted with tape spacers to hold the samples upright and separated

[127] NORMAL 11/85, Draft translation by E. Charola; RILEM Test No 11.6; Massari and Massari, 21-31; Vos, "Water Absorption and Drying of Materials," 679-694, Vos, "Moisture in Monuments," 147-153, Charola, Advanced Conservation Science Laboratory "Water Absorption and Drying Behavior."

through the testing. The baskets were placed on glass rods in a large polyethylene container and distilled water was added so that only the bottom 1 cm of the disc contacted the water. The contact surface arc was determined to be 4.5 cm, so the contact surface area of each disc edge was calculated using the 4.5 cm arc and the sample thickness. Calculations were made for density, surface area, volume, and contact area for the stucco discs and the brick cubes. The brick cubes were placed directly on glass rods in a separate polyethylene container. For those brick cubes that contained stucco, the stucco surface was positioned at the side of the sample, so that capillary water rise would occur as it would on a tomb wall. Distilled water was added so that only the bottom 1 cm of the cube contacted the water. The contact surface area used was the calculation of the area of the cube face contacting the water.

At predetermined times, samples were removed, blotted dry and weighed throughout the 9 day test. The containers were kept sealed between weighings to keep the chambers at 100% RH, and as needed, distilled water was added to keep the samples in contact with the water.

After all samples had reached a constant capillary absorption state, W_{CAP}, where the differences in moisture absorption between weighings were all less than 0.1%, the samples were fully immersed in distilled water for another 24 hours and then weighed

for the fully saturated weight, M_{SAT}. The differences between M_{SAT} and W_{CAP} were small, as could be expected for such porous materials.[128]

Fig. 5.19 Stucco discs racked in water for capillary absorption test.

Fig 5.20 Sample from Tomb #275, Gray Group stucco showing salts from the stucco forming at the interface of brick skin during the capillary absorption test.

The amount of water absorbed per unit surface, M_i (g/cm^2) was calculated and plotted against the square root of time to create the capillary absorption curves for each sample. The initial straight part of the curves was used to calculate the capillary absorption coefficient, which is the slope of that part of the curve, expressed in g/cm^2 $sec^{0.5}$. Calculations were made to determine the individual capillary absorption rates by sample and the results were then grouped and averaged to compare data between stucco and brick types.

[128] Massari and Massari, 22-25.

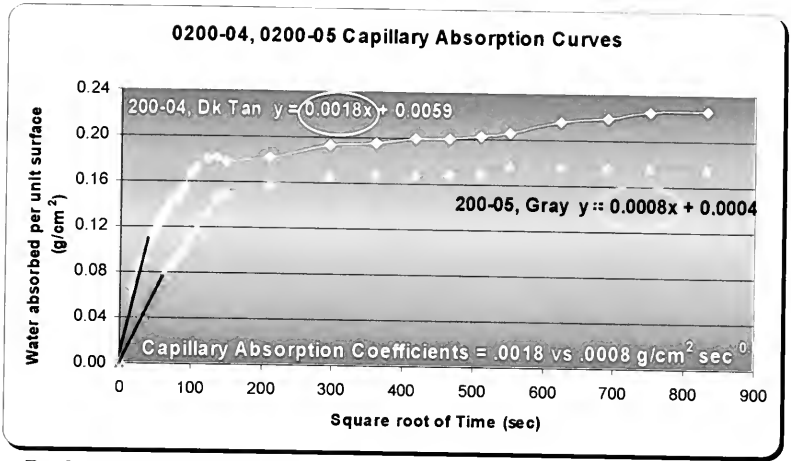


Fig. 5.21 Capillary absorption curves.

The total water absorbed, or the Imbibition Capacity, was calculated:

$$(M_{SAT} - M_{DRY})/M_{Dry} \times 100 = \text{Imbibition Capacity \%}$$

This test confirmed the results from the total immersion tests of both stucco and brick groups. The White group stucco is almost as absorbent as the River brick, and slightly more absorbent than the Lake brick. The Gray group is less than half as absorbent as are the bricks. The capillary absorption coefficient calculated for these samples provides an indication of the pulling power of each group when placed in contact with water through rising damp or rainfall. All stucco groups have much lower capillary absorption coefficient values, which would be beneficial in their exterior protection role. The high coefficients for the brick samples are consistent with the observed condition of damp interior bricks resulting from capillary action (rising damp).

Table 3

Summary Results from Capillary Absorption Test

Stucco Without Surface Finish, Bare Brick

Sample Type	Cap. Absorp Coeff. $g/cm^2\,sec^{0.5}$	Imbibition Capacity %
Gray Stucco	0.0019	9.04%
WhiteGray Stucco	0.0023	11.05%
DkTan Stucco	0.0024	11.73%
Tan Stucco	0.0025	12.21%
White Stucco	0.0052	23.02%
Lake Brick	0.0341	18.18%
River Brick	0.0471	23.93%

5.2.7 Drying Curves and Drying Rates

The methodology for the determination of drying rates was adapted from the NORMAL and RILEM published test methods, the work of Massari and Massari and Vos, and the laboratory developed by E. Charola.[129] The fully saturated samples of stucco and brick were removed from the water. The stucco samples were placed in the dry open wire baskets adapted with tape spacers, and the brick cubes were placed on dry glass rod supports and weighed at predetermined times. The sample containers ensured a draft free environment. All weights were made on the ACB 300 balance at ±0.01

[129] NORMAL 29/88. Draft translation by E. Charola; RILEM Test No II.5; Massari and Massari, 21-31;Vos. "Water Absorption and Drying of Materials," 679-694, Charola, Advanced Conservation Science Laboratory "Water Absorption and Drying Behavior."

g accuracy. The stucco samples were dried for 3.5 days and the brick samples for 4.5 days. After the drying period, the samples were dried at 83°C for 12 hours and re-weighed.

Using the data from the drying test, drying rates were calculated and curves were developed to determine the critical water content (Ψ_c). None of the curves graphed with the exact shape and precision of those seen in the Vos, Massari and Massari and other published test methodology literature.[130] According to RILEM Test No. II.5, multi-dimensional evaporation, form of the sample, initial water content, material properties and boundary conditions can all affect the shape of the curve.[131] However, the curves do show the distinct drying phases and the bending point and can be used to describe differences between materials.

For Tomb #600, the Tan stucco layer alone was compared to stucco containing a layer of Gray stucco over the older Tan stucco, as is currently on the tomb. In both curves, the initial decrease in rate of drying occurs during the first 30 minutes, when the exterior adsorbed water of the very wet outer surface evaporates. In the single layer Tan stucco, the primary diffusion phase is relatively flat and continues until only 0.017 g/cm^3 of moisture is left in the sample.

[130] The graphs referenced do not include a sharp curve change at the initiation of the test. Those tests started with samples at the maximum point reached through capillary absorption, as compared to this research which started measurement of the drying curve at the saturation point after total immersion.
[131] RILEM No II.5, p 2.

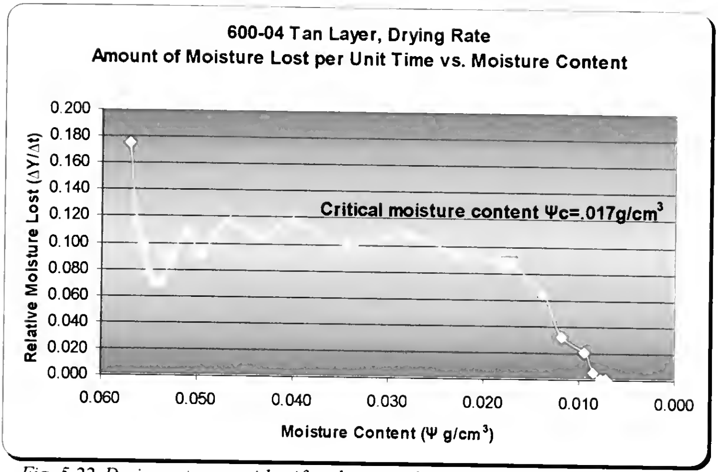
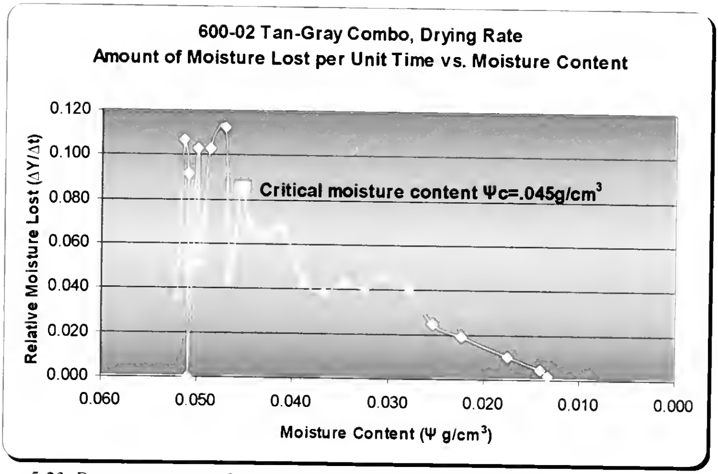


Fig. 5.22 Drying rate curve identifies the critical moisture content point.



5.23 Drying rate curve for a combination sample.

The combination sample is much more erratic, which can be explained by the differential evaporation happening on the two sides of the sample. The very high initial rates might also represent the Tan layer pulling moisture from the Gray layer. The critical moisture point of the system is high at .045 g/m^3. On the tomb, the Gray layer would restrict the ability of the brick and Tan layer to dry, keeping the inner materials damp longer than the Tan layer alone.

Table 4
Summary Results from Drying Rates
Stucco Without Surface Finish, Bare Brick

Sample Type	Critical Moisture Content	Critical Moisture Content %
Gray Stucco	0.0364	82.57%
WhiteGray Stucco	0.0380	80.06%
DkTan Stucco	0.0272	51.72%
Tan Stucco	0.0309	53.86%
White Stucco	0.0215	33.68%
Lake Brick	0.1532	48.51%
River Brick	0.0313	7.60%

5.2.8 Acid Soluble Analysis & Gravimetric Analysis

The literature includes multiple articles describing the basic mortar analysis techniques.[132] Most rely on a crushed sample, digested in acid, filtered, with a weight calculation made for the fines, percent soluble and percent insoluble (aggregate) fractions. The insoluble fraction is then sieved through multiple screens to separate the aggregate by size. Each of these fractions can then be further analyzed by microscopy or more advanced chemical analyses. Such basic methodology yields much information on the mixture and is particularly helpful in preparing replacement mortars that will be similar in color, texture and component ratios. The method does not allow an exact accounting of the original binder to aggregate ratio, the methods used for mixing and placing the mortar, the rate of drying or the mineralogical identification of binder and aggregate. Calcareous binders, some silicates and clay impurities can react with hydrochloric acid, skewing the results and obscuring the identification of the binder. Petrographic analysis with the microscope and X-Ray diffraction are often used for mineralogical identification, and the acid digestion solute can be further analyzed by acid/base titration, Infra-Red spectroscopy or other analytical techniques.

[132] ASTM C136-84a Standard Method for Sieve Analysis of Fine and Coarse Aggregates; Teutonico, 113-115; E. Blaine. "Tests for the Analysis of Mortar Samples." *APT Bulletin* Vol. VI No. 1 (1974): 68-73; Matero. ACS Laboratory Experiment #9, "Mortar Analysis, Simple Method."

There are many articles listed in the Bibliography that present work on methodology to simplify or make the basic mortar analysis technique more informative. For this research, the general properties and any differences between the 4 stucco types and the mortar were the reasons for mortar analysis, and only a few samples were further analyzed microscopically and through XRD, SEM and TGA. The "Simple Method of Mortar Analysis" was used, adapted from instructions in the *ARC: A Laboratory Manual for Architectural Conservators*. An example of the mortar analysis worksheet developed to document all observations and results gathered during the analysis is included in Appendix C.

The samples chosen for analysis were crushed finely with a mortar and pestle, and then dried in a 100°C oven for 24 hours. The target size for the sample was 50 g, however, due to availability, most samples only yielded 20-30 g for testing. Samples were each characterized for color using the Munsell Soil Charts (ASTM D1535-97), texture and hardness. No foreign organic matter (beyond biological growth) was detected in any of the samples. Where a sample contained crushed shell, brick or charcoal, it was noted.

The dry sample to be digested in acid was weighed, then placed in a 600ml beaker and moistened with water. Hydrochloric acid at 4M concentration was slowly added to the beaker and the type, intensity and bubbling of the reaction was recorded using a 0 to 3 scale, with 3 being most aggressive, or largest, long lasting bubbles. More acid was

added over an 8 hour period of digestion until no further reaction was evident. After 8 hours, the acid digestion solution was carefully diluted with distilled water and the liquid was stirred to levitate the fine particles, separating them from the heavier or larger particles at the bottom of the beaker. The solution was poured into a volumetric flask through a funnel with weighed filter paper. The coarse fraction was washed numerous times to ensure that all acid and fines were separated. The color of the filtrate was noted.

The fines and filter paper were dried for 24 hours and weighed. The coarse fraction was allowed to dry in the beaker overnight, then was transferred to a metal weighing dish and dried for 12 hours and weighed. The weight of the fine and coarse fractions were subtracted from the initial dry weight to calculate the weight of the acid soluble fraction and all fractions were expressed as a w/w%. Using volumetric conversion estimates by Cliver, an estimate was also made of the v/v% to determine original mixing ratios.[133] The color of the fines was characterized by Munsell Soil Charts (ASTM D1535-97).

The coarse fraction was sieved in a standard soil analysis sieve set with 7 screens (2.36mm, 1.18mm, 600μm, 300 μm, 150 μm, 75 μm and <75 μm.) according to ASTM C136-84a. The amount collected in each screen was weighed and calculations and

[133] Cliver, 70.

graphs were made showing the distribution of the aggregate in the coarse fraction by percentage and by cumulative percent retained. The amount of aggregate that remained in the <75 μm pan was then subtracted from the coarse fraction and added to the fines fraction. The sieved aggregate was inspected and photographed with the Reflected Light, Nikon SMZ-U Microscope and Nikon AFX II A Camera at 5X and the images were included in the Mortar Analysis Worksheet.

In Figure 5.24 below, the weight percent distribution of Fine, Coarse and Acid Soluble fractions are compared for the 5 stucco groups and the mortar. The mortar samples had significantly higher fines fractions than did the stucco samples and the fines were generally a Munsell 10YR or 7.5YR with a reddish clay or fine silt appearance.

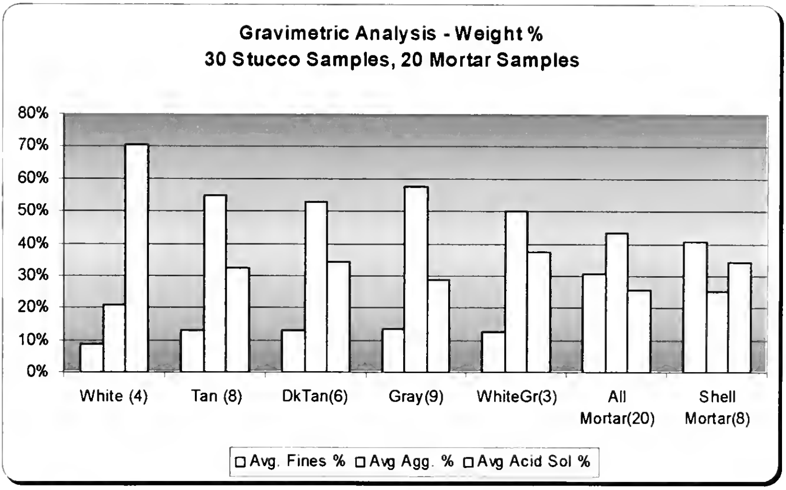


Fig. 5.24 Weight % averages for fine, course and acid soluble fractions by group.

The mortar samples varied widely in reaction aggressiveness and in mineralogical components in the coarse fraction. A group of 8 samples appeared to be poorly digested because of a "shell" of matte white material that coats the particles, often in all fractions. An example of this can be seen in Figures 5.25 and 5.26. These samples all had very aggressive reactions and large long lasting foam. These samples have a much lower aggregate content than do the other mortars and all stucco samples tested.

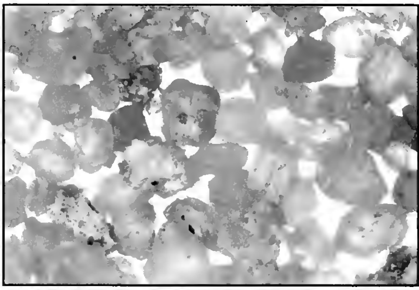


Fig. 5.25 09-03 Mortar, Sieve Fraction 1, 2 and 3. 5x magnification.

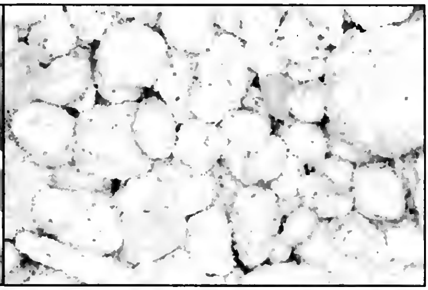


Fig. 5.26 45-03 Mortar, Sieve Fraction 1, 2 and 3. 5x magnification.

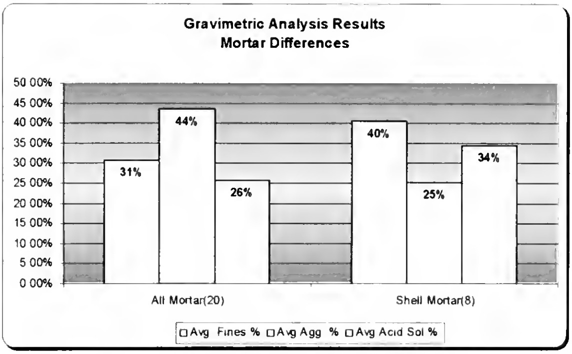


Fig. 5.27 Mortar type differences – Gravimetric analysis results.

The aggregate fractions in the mortar samples showed a definite skew to the finer aggregate sizes with the shell group showing the most dramatic skew to 75µm. The stucco groups, in comparison, were all well sorted and the distribution in aggregate size was very similar between stucco groups, with the Tan and Dark Tan groups having the closest distribution around 300 µm.

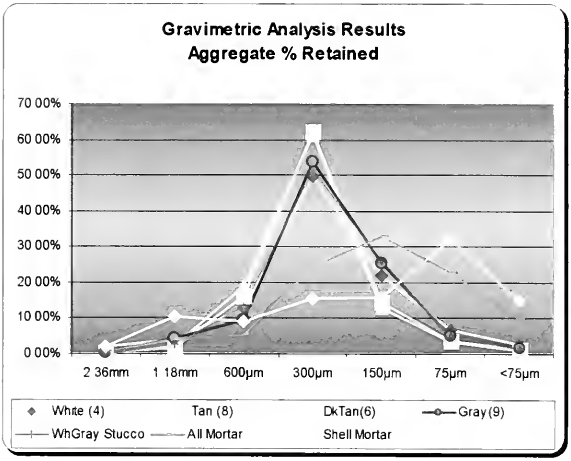


Fig. 5.28 Aggregate analysis, % retained.

The fact that the aggregate becomes more sub-angular in the Dark Tan and Gray group may be an indication that hydraulic mixtures (natural cements) containing non-local sands are being used. The local sands came originally from upriver stones, and when deposited by the Mississippi River, were sub rounded as the result of hundreds of millions of years of weathering and water polishing.

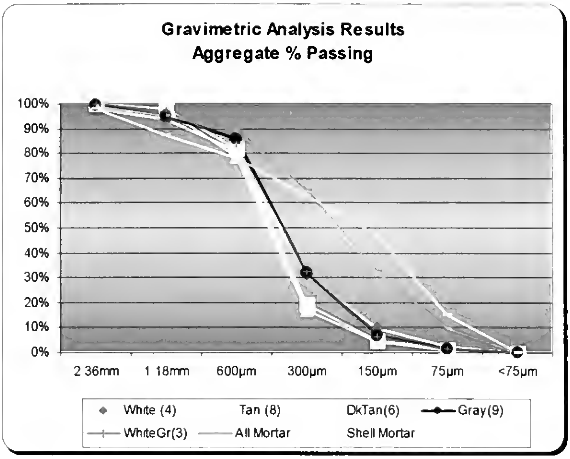


Fig. 5.29
Aggregate analysis,
Same results expressed
as % passing.

After considering the differences exhibited by the mortar samples, the samples in the different stucco groups show much greater similarities in the distribution between fines, coarse and acid soluble fractions. The White group, expected to be primarily lime, had a significantly greater acid soluble fraction, while the other groups varied only a minor amount.

The White group of 4 samples had the most aggressive reaction to the addition of acid, with big frothy bubbles and a resultant solute of gold/yellow to light yellow. The rounded to sub-rounded aggregate showed no signs of incomplete digestion, was primarily of clear and yellow quartz and all fractions of all samples contained particles of brick. There were also lustrous black particles in each fraction of each sample. Black sand is generally quartz with iron impurities, such as ilmenite (FeTiO3),

magnitite (various iron silicates) or particles of feberite (FeNO4).[134] The sample from the oldest wall vault, #1200, also contained dull greasy black particles, suspected to be charcoal. Sample #200-03 was unusual in the overwhelming amount (>40%) of brick particles and it is thought that this "patch" on the outside of one wall was an experiment with local lore that describes added brick dust as both a colorant and hydraulic component. The Munsell color of the fines for all other White group samples was 2.5YR 6/1. The very high ratio of acid soluble fraction to fines and aggregate to acid soluble is distinctively different in this group from the other stucco groups.

The 8 samples from the Tan group and 6 from the Dark Tan group came both from tombs of a single layer and from the combination tombs of a Gray layer over an earlier layer. The Gray results are in the discussion below. The Tan group did not react with acid as aggressively as the White Group, with only 3 of the 8 samples having a reaction rated at "3 = Most Aggressive" and with less foaming that died down more quickly. The solute was generally light yellow. Most of the samples were fully digested, and of the few that were not, the remaining binder on the aggregate did not react to HCl when later tested, indicating components that were not soluble. The sub-rounded aggregate included more yellowed or cloudy appearing quartz, small amounts of clear amber to brown particles and most fractions contained some of the particles containing iron. Brick particles were seen in 5 of the 8 samples in small quantities and 6 of the 8

[134] Sybil T. Parker, ed. *Dictionary of Scientific and Technical Terms*, New York: McGraw Hill, 1983.

samples showed considerable shell particles in the finer fractions. The color of the fines varied, particularly in darkness of shade, but all were either Munsell 7.5YR or 10YR and none had a gray appearance.

The Dark Tan group reacted to the addition of acid in a similar manner as the Tan group. The solute was generally light yellow. There were 2 samples that did not fully digest. When tested later with HCl, the remnants did not react. The aggregate tended to be both sub-rounded and sub-angular and many of the fractions had dark beige clusters that also did not react when drop tested with HCl. Brick was evident in 3 of the 6 samples, but only in small amounts. There were more black iron containing particles than had been seen in the Tan group. All but one of the fines were rated Munsell 7.5YR with most being on the 7.5YR 6/x level. None had a gray appearance.

The Gray group samples were those suspected to contain modern Portland cement. These samples reacted the least aggressively to acid digestion and 7 of the 9 samples did not fully digest, 4 of which later reacted to HCl and 3 of which did not. The solute was generally light yellow to greenish yellow and 2 of the samples had green frothy bubbles. The primarily quartz aggregate was sub-rounded and sub-angular, and contained bright orange and shiny yellow sub-angular particles. There were also light gray to bluish gray particles in both lustrous and dull forms and the finer fractions often contained many flat white crystals which were not shell and which did not react at all to

HCl. The color of the fines was predominantly gray to gray/white with 6 of the 9 samples rated Munsell Gley1 8/N, one at Gley1 7/N, and the rest were one of the light grays on the Munsell YR pages.

The White Gray group was initially included in the Gray group, but the samples were found to differ significantly. Only 3 were tested and all reacted aggressively upon exposure to HCl. All did not digest completely, but the remains did not react to spot testing with HCl. The aggregate for these samples contains some of the same bright orange and yellow particles as did the Gray group, as well as more of the black iron containing particles in each sieve fraction. Most notable was the high level of the flat white particles in the finer fractions. These particles did not show any bi-refringence when tested later on the polarizing microscope and it is expected that they are china clay, often added to white Portland cement in place of the iron oxides.

Few definitive conclusions can be made based on the results of these 30 stucco and 20 mortar samples, except that the mortars consist of a greater percentage of fines which appear to be clays and silt. The high acid soluble fraction in the White group confirms the high proportion of lime suspected in the binder. Both the Tan and Dark Tan groups contained non-digested particles that may be from the burning of clay containing hydraulic lime. There is a great diversity between samples within each group and more analysis of a

greater number of samples would be advisable to be able to fully characterize the stucco and mortar at St. Louis Cemetery No. 1.

Table 5
Gravimetric Analysis Weight % Results

	Stucco Samples (30)					Mortar (20)	
Weight %	**White (4)**	**Tan (8)**	**DkTan (6)**	**Gray (9)**	**WhGr (3)**	**All (20)**	**Shell Type (8)**
Average Fines %	8.57%	13.12%	12.97%	13.48%	12.43%	30.85%	40.41%
Average Agg. %	20.92%	54.73%	52.83%	57.55%	50.05%	43.53%	25.16%
Average AcidSol %	70.51%	32.15%	34.21%	28.96%	37.52%	25.62%	34.43%
Approx. Ratio (w/w%)	1 / 2.4 / 8.2	1 / 4.2 / 2.5	1 / 4 / 2.6	1 / 4.7 / 2.1	1 / 4 / 3	1.2 / 1.7 / 1	1.6 / 1 / 1.4
Fines+AcidSol :Agg	7.3 / 1	1 / 1.2	1 / 1.1	1 / 1.3	1 / 1	1.3 / 1	3.2 / 1
Average Reaction	3+	2.38	2.33	1.67	2.33	2.45	3.00
Average Bubbles	3+	2.75	2.50	1.78	2.33	2.45	3.00
% Retained							
Sieve 1 – 2.36 mm	2.08%	0.20%	0.14%	0.29%	0.00%	0.74%	1.93%
Sieve 2 – 1.18 mm	4.03%	1.58%	2.40%	4.52%	2.77%	4.23%	10.50%
Sieve 3 – 600 μm	12.73%	16.31%	19.01%	9.32%	13.24%	5.53%	9.21%
Sieve 4 – 300 μm	49.71%	62.30%	61.32%	53.78%	51.49%	24.42%	15.43%
Sieve 5 – 150 μm	21.94%	14.52%	12.80%	25.23%	26.18%	32.69%	15.88%
Sieve 6 – 75 μm	6.92%	3.83%	3.37%	5.20%	5.04%	22.65%	32.23%
Pan (7) - <75 μm	2.59%	1.26%	0.96%	1.66%	1.28%	9.73%	14.83%

5.2.9 Calcimetry

It was planned to use the calcimeter to determine that part of the acid soluble fraction that could be totally attributed to carbonates ($CO_3^{=}$) which produce CO_2 upon dissolution in hydrochloric acid. The reaction that occurs is:

$$CaCO_3 + 2\ HCl \rightarrow Ca^{++} + 2\ Cl^{-} + H_2O + CO_2$$

This can help determine whether a mortar is totally lime based or whether it includes other hydraulic components. The clay impurities and the silicates from hydraulic lime, natural cement and Portland cements can be partially dissolved in the acid soluble method. The calcimeter identifies that part of the soluble fraction that is made up of carbonates only, allowing finer differentiations to be made.

However, the calcimeter method is very prone to both equipment and operator error. Several tests resulted in erratic results, and it was decided that this test would not be used. The methodology does have merit and should be included in any future research. To be used, it would be necessary to have more samples so that more repetitions could be made to reduce operator error and make the data statistically reliable. According to Teutonico, "In actual practice at ICCROM, the test has proved less reliable and consistent than simple mortar analysis. This may be due to problems with the instrument or with the formula and constant used for calculations."[135]

[135] Teutonico, 117.

5.2.10 Presence of Salts

Salts were not observed to be a persistent problem at St. Louis Cemetery No. 1. However, each of the stucco samples ground for mortar analysis, and a small amount of dissolved brick and solution from the brick total immersion test, were tested for the presence of water soluble salts, including sulfates, chlorides, nitrites, nitrates and carbonates.[136]

Samples were placed in 10 cc test tubes and filled half-way with distilled water and shaken gently. After the insoluble portion of the sample had settled to the bottom of the test tube, a small amount of liquid was poured into 3 additional 10 cc test tubes.

To analyze for sulfates (SO_4^-), 2 drops of 2N hydrochloric acid (HCl) and 2 drops of a 10% solution of barium chloride ($BaCl_2$) were added to the first test tube. A white precipitate of $BaSO_4$ would indicate the presence of sulfates.

$$SO_4^- + BaCl_2 \rightarrow BaSO_4 + 2Cl^-$$

Only 4 stucco samples showed any sign of sulfates and none of the brick solutions tested positive.

[136] Teutonico, 58-65; NORMAL 13/83 Determination of Total Amount of Soluble Salts.

To analyze for chlorides, 2 drops of nitric acid and 2 drops of silver nitrate ($AgNO_3$) were added to the second test tube. A whitish-blue, gelatinous precipitate of silver chloride (AgCl) would indicate the presence of chlorides.

$$Cl^- + AgNO_3 \rightarrow AgCl + NO_3^-$$

Only 2 stucco samples showed any indication of chlorides. Of the brick solutions, 3 of the lake bricks and 1 of the river bricks showed a slight positive indication.

To analyze for nitrites (NO_2^-) 2 drops of dilute acetic acid (CH_3COOH) and 2 drops of Griess-Ilosvay's reagent were added to the third test tube. A pink color would indicate the presence of nitrites.

When the solution did not turn pink, an analysis for nitrates (NO_3^-) was run on the same test tube. A small amount of zinc powder was added. Zinc reacts in the presence of acetic acid to convert nitrates to nitrites, if present, and a pink color would result. None of the samples showed the presence of nitrites, and when zinc was added, none showed the presence of nitrates.

To analyze for carbonates, the insoluble residue in the bottom of the original test tube was tested with 2 drops of 2N HCl. All of the stucco samples reacted positively to this test and none of the bricks were affected. The reaction:

$$CaCO_3 + 2\ HCl \rightarrow CaCl_2\ (\text{soluble}) + H_2O + CO_2\ (\text{gas})$$

The chemical spot tests for salt presence produced minimal results (except for carbonates on the stucco). This confirmed the field observations and the tests that had been conducted to identify salts during the *Survey*. However, to look more closely at the possibility of salt presence, another test tube per sample was prepared to retest the stucco samples using indicator strips. Merckoquant® strips were used to test for presence of sulfates, chlorides, nitrites and nitrates. Again, no sample showed evidence of nitrites or nitrates. In the chart below a "+" for chloride indicated 1000 mg/l Cl^- and a "+-" indicated 500 mg/l Cl^-. Only sample #200-05(Gray) tested at over 800 mg/l sulfate and all others that tested positive were between 400 and 800 mg/l sulfate. These results indicate that a small amount of salts are present to take part in the decay mechanisms. Most of the stucco sample layers that tested positive for sulfates are from tombs with multiple layers of stucco, where at least one of the other layers is of cement.

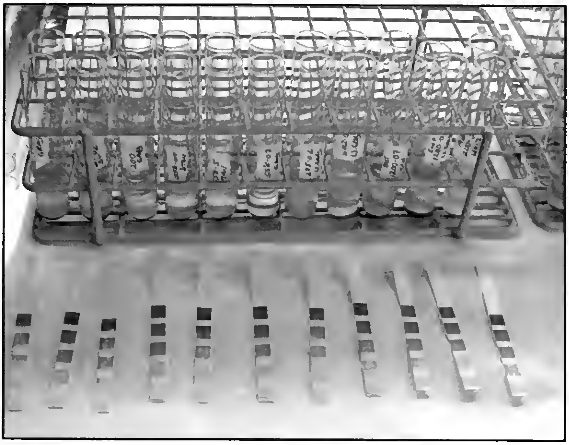


Fig. 5.30 Testing for salts with Merckquant® indicator strips.

Table 6

Qualitative Analysis for Soluble Salt

Sample	Sulfates	Chlorides	Sample	Sulfates	Chlorides
White			**Dark Tan**		
200-03	+-	+-	89-02	+-	+-
259-04		+	573-03		+-
1200-02		+-	107-03	+-	+-
Tan			200-01	+-	+-
45-01		+-	39-02		+-
548-02	+-	+-	558-04		+-
13-01		+-	**Gray**		
600-04	+-	+-	44-01	+-	+-
09-08		+-	581-01	+-	+-
14-01			1300-01	+-	+-
558-05		+-	600-02	+-	+-
1200-07		+-	09-07		+-
White Gray			14-02		
275-02		+	39-01	+-	+
602-02	+-	+-	200-05	+	+
1200-01	+-	+	558-07	+-	+-

5.2.11 Optical Microscopy

Reflected and transmitted microscopy are both useful in mortar and surface finish analysis. At the optical level of magnification, the differences in aggregate and binder paste can be compared for color, porosity and components. In the samples prepared for this research, the hypothesis was that the cement binder paste would appear finer with lower porosity and that it might be possible to see areas of damage from the formation

of expansive salts.[137] Hydration products often can be seen as a rim around quartz on both the cement and hydraulic lime mortar. If the mortar is hydraulic due to the addition of pozzolans, this can often be noticed in optical microscopy, as the pozzolans can be seen and a hydration ring is sometimes visible around the particle.

Several representative samples were prepared from each of the stucco type groups. A small chip was cut showing the area of interest and was embedded in a catalyst setting polymer (Bioplast®). Thick sections were made with two parallel cuts with the Buehler Isomet® low-speed diamond blade. The samples were each hand polished on a Buehler polishing cloth with a small amount of water and 0.05 μm alumina powder and then affixed to a glass slide with Duco® cement. Before viewing, a temporary cover glass was attached with a drop of Stoddard's solvent.

An example of the differences that can be seen in samples by reflected light microscopy is illustrated by Figures 5.31 and 5.32. Both samples are from Tomb # 09, which is an early platform tomb with a first visible date of 1822. It has been encased in heavy cement. The cross-sections were photographed at 12.5x magnification. While not always the case, the tombs that had multiple layers generally did have a more

137 A. Moropoulou, A. Bakolas, and K. Bisbikou. "Physico-Chemical Adhesion and Cohesion Bonds in Joint Mortars Imparting Durability to the Historic Structures." *Construction and Building Materials* 14 (2000): 35–46; K. Callebaut, J. Elsen, K. Van Balen and W. Viaene. "Nineteenth Century Hydraulic Restoration Mortars in the Saint Michael's Church (Leuven, Belgium) Natural Hydraulic Lime or Cement?" *Cement and Concrete Research* 31 (2001): 397–403.

porous paste in the inner, older layer and denser matrix in the outer layer. The optical appearance correlated with the density data developed in the capillary absorption test.

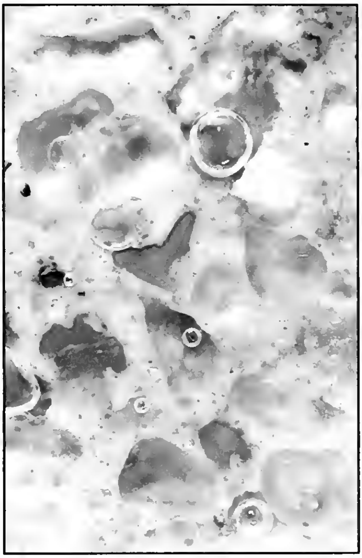


Fig. 5.31 Tan layer on Tomb #09. 12.5 x.

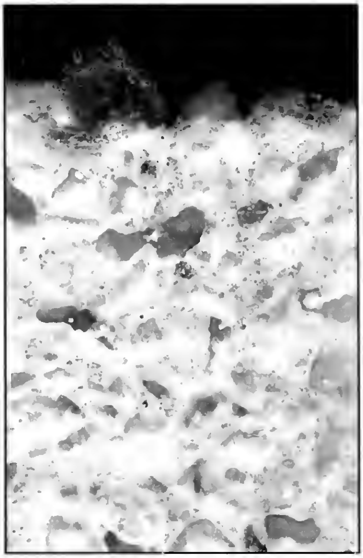


Fig. 5.32 Gray layer on Tomb #09. 12.5 x.

Figures 5.33 and 5.34 show the mortar from Tomb #09. In the paste, brick dust can be seen, as can a piece of shell. The paste is a very different consistency and porosity than either of the stucco layers.

Although each of the samples was carefully inspected at both 12.5 x and 25 x magnification, no evidence of hydration rings or damaging salt formation could be seen. Only one sample, seen here in Figure 5.35, showed damage between the stucco

layers. It was determined that while thick sections might be very appropriate for surface finish analysis, they are not the best choice for micro-structure.

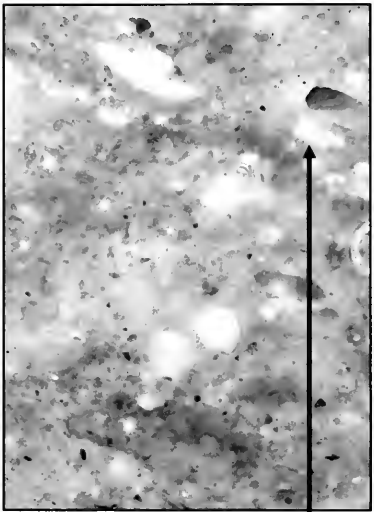


Fig. 5.33 Tomb #09 Mortar, 12.5 x Magnification, Layer of brick particles evident.

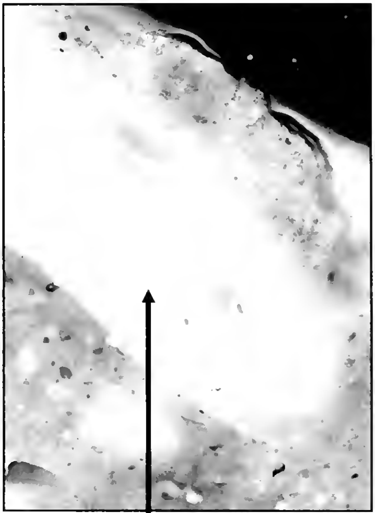


Fig. 5.34 Tomb #09 Mortar, 12.5 x Magnification, shell fragment in matrix.

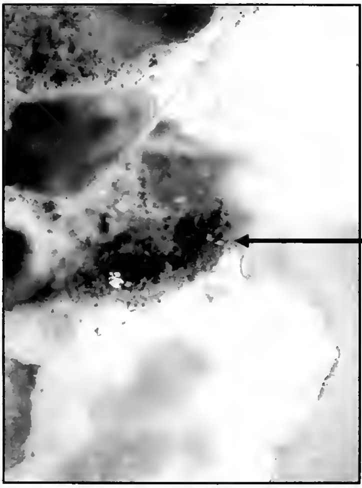


Fig. 5.35 Tomb #600, The black area between the gray and tan sections of the image is the damage detected between the original tan and newer gray layers of stucco. 25 x magnification.

5.2.12 Polarized Light Microscopy

Polarized light aids in the identification of minerals by their different crystalline shapes, indices of refractions and configurations. Most of the studies published rely on optical microscopy of disperse or thin sections for petrographical and mineralogical characterization of the constituents, the different mineral phases in the paste and the relationship between binder and aggregate.

Several representative disperse samples were prepared from each of the stucco color groups to identify aggregate minerals. For most of the samples, the fractions for Sieve 4 and Sieve 5, 300 μm & 150 μm, were used, as these fractions tended to contain the most non-quartz aggregate for most of the samples. For Tombs #09, 200 and 600, disperse samples were also prepared of the fines and these samples were also analyzed by XRD. The samples were dispersed on a glass slide using a needle, while viewing the dispersion under a student microscope. Once the dispersion was suitable, a round glass cover slip was gently laid over the sample and several drops of melted resin (refractive index of 1.66) were touched to the side of the cover slip. Capillary action pulled the resin under the slip to secure the sample.

Polarized light microscopy allows observation with transmitted plane polarized light and cross-polarized light provided by a quartz halogen light source. The light rays are

"polarized" or brought into the same propagation direction by the condenser below the sample. The analyzer contains the second polarizing filter. When engaged, it can be used to look at samples with the poles crossed perpendicularly, or slightly off-crossed. Under the crossed poles, the only light and colors visible will be those that the sample allows through based on refractive index and birefringence. The different crystalline phases of inorganic materials can be identified by their refractive index, amount of birefringence, color, crystal size, fractures and shapes. Determining these properties allows identification using resources such as the *McCrone Particle Atlas.*[138]

For each sample analyzed, the Becke Line was determined for selected particles. A faint halo can be seen around particles under plain polar light. As the fine focus is turned slightly forward, and the sample loses focus, the halo moves in the direction of the higher refractive index. Since the disperse samples are embedded in a medium with a refractive index of 1.66, it can be determined whether the sample is above or below 1.66. The sample was then viewed under cross-polarized light and the birefringence of the different particles was noted, as were any differences in the type of extinction.

[138] Walter C. McCrone and John Gustav Delly, *The Particle Atlas, Vol. I Instrumentation & Techniques* (Ann Arbor: Ann Arbor Science Publishers, 1973). The same information has been incorporated into a searchable CDRom published as The Partical Atlas Electronic Edition (PAE2), copyright 1992 by MicroDataware..

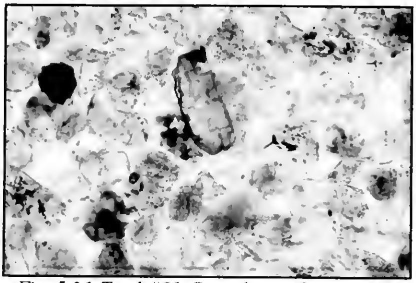


Fig. 5.36 Tomb #89, Particle size from 150-300μm, Transmitted – plain polarized light. 25 x Magnification.

Fig. 5.37 Tomb #89, Particle size from 150-300μm, Transmitted – crossed polarized light. Primarily quartz, seen here as highly bi-refringent. 25 x Magnification..

Using this information collected on several of the aggregate particles of interest, the *Particle Atlas* was consulted. The *Particle Atlas* confirmed the overwhelming presence of highly refractive quartz, seen above in the comparing plain polarized vs. cross polarized transmitted light. The *Particle Atlas* was very not useful in determining the small colored aggregate particles.

For one of the tombs, Tomb #09, a thin section slide was prepared to investigate the total system of brick and stucco layers. A large fragment of stucco containing a piece of brick substrate was marked for cutting and sent to an external service for thin section preparation. The slide was cut thin enough so that it could be viewed under transmitted polarized light. The slide was stained on one half with alizarin red which highlights any calcite in the sample.

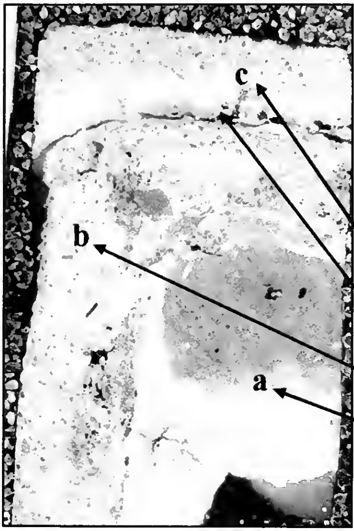


Fig. 5.38 Block of embedded sample showing orange colored brick (a), the original Tan stucco layer(b) and the cement coating (c). The blue polymer used for embedding is forced through the pores and will show up in the thin section. This enables easy identification of pore vs. matrix vs. aggregate.
In Tomb # 09, there is delamination between the stucco layers evident, as can be seen in this sample.
1.5x magnification.

Gray (c)

Tan to Gray Interface

*Original Tan (**b**)*

*Brick (**a**)*

On the following page, photomicrographs of the original Tan group stucco are compared to those of the Gray group stucco. On the left can be seen a clear indication of calcite present through the staining from Alazarin Red on the left sides of both images. The right images show the same portion of the cross-section under cross polarized light. The predominant aggregate in each sample is quartz, however, grain size and shape is quite different.

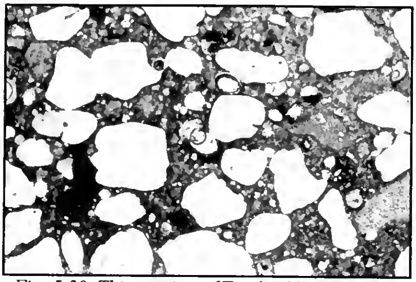


Fig. 5.39 Thin section of Tomb #09, Tan layer Transmitted, plain polarized light, 12.5 x magn..

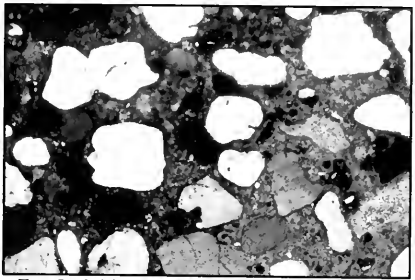


Fig. 5.40 Thin section of Tomb #09, Tan layer Transmitted cross polarized light, 12.5 x magn.

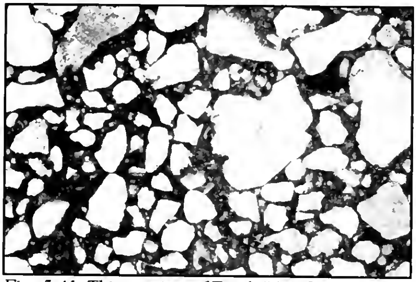


Fig. 5.41 Thin section of Tomb #09, Gray layer Transmitted, plain polarized light, 12.5 x magn.

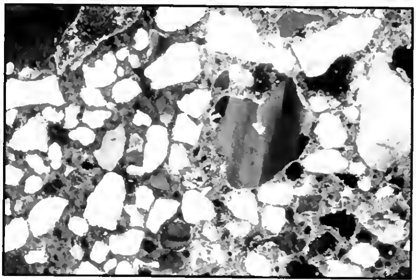


Fig. 5.42 Thin section of Tomb #09, Gray layer Transmitted cross polarized light, 12.5 x magn.

5.2.13 Advanced Instrumental Analysis

Several samples were selected for advanced testing at the Laboratory for Research on Structural Matter.[139] It was hoped that hydraulic lime could be identified as a component in the tan stuccos (Tomb # 09 and 600) and that moisture driven damage products between layers could be detected. Research has been conducted on cement vs. hydraulic lime vs. lime and has developed several key identification aids. Lime stucco should be primarily of calcite ($CaCO_3$) or dolomite ($MgCO_3$). Cements should be dominated by the hydraulic component C_3S (tricalcium silicate), while hydraulic lime should contain predominantly C_2S (dicalcium silicate) in addition to calcite ($CaCO_3$). Damaging salts from sulfate attack in cement such as ettringite ($C_3A{\cdot}3CaSO_4{\cdot}32H_2O$), tobermite ($Ca_5Si_6(O, OF, F)_{18}{\cdot}5H_2O$) or thaumasite ($CaCO_3{\cdot}CaSO_4{\cdot}CaSiO_3{\cdot}15H_2O$) might be detectable, and the cement crystalline phases should be visible under SEM.

5.2.14 Scanning Electron Microscopy, EDS

Most of the research studies on historic mortars in the attached bibliography include SEM (Scanning Electron Microscopy) in their analysis, often coupled with EDX/EDS (energy dispersive X-Ray micro-analysis), to examine the micro-structure of the mortar

[139] Jim Ferris conducted and explained the significance of the SEM and EDS tests. Bill Romonow conducted and analyzed the findings in XRD and Andrew McGhie conducted and analyzed the TGA/DTA scans.

and study the interface between components in very high magnification. Callebut, et. al. used SEM in backscatter mode (BSE) on polished cross-sections to identify the different hydraulic phases in a mortar from St. Michael's Church in Leuven, Belgium. EDX was used to quantify the different atomic ratios of each of these phases.[140] Riccardi, et.al. used optical microscopy in the characterization of mortar samples into groups for analysis, followed by SEM and EDX. Their images clearly show dicalcium silicate (belite) and tricalcium silicate (alite), both well known cement phases, and the needle-like prismatic hexagonal crystals of ettringite.[141]

Scanning Electron Microscopy, or SEM, is useful to determine the micro-morphology of materials under study. A highly focused beam of electrons irradiates the surface of a sample, exciting the molecules of the material, which give up secondary electrons. These are collected and computer manipulated to create a black and white image made up of the point-by-point energy signals, resulting in very clear images of the sample topography. At high magnifications, clear images of the crystalline shapes can be seen. The SEM depth of field is much greater when compared to light microscopy. The beam of electrons is able to pass through the sample, revealing much more of a 3-dimensional sample than is possible with a light wave, the source in the polarized light microscopes discussed above. For building materials like stone, mortars and stucco,

[140] Callebaut, et. al., 397-403.
[141] M.P. Riccardi et. al., "Thermal, Microscopic and X-Ray Diffraction Studies on Some Ancient Mortars." *Thermochimica Acta* 321 (1998): 207-214.

this allows the porosity and the inter-relationship of crystals and the cementatious binding materials to be seen. An experienced user can recognize the crystal shapes and sizes as specific compounds, or as stages of their crystalline development.

For this research, three stucco samples from the St. Louis Cemetery No. 1 project were mounted for study. The samples were affixed to a metal "stub" using carbon coated double-stick tape. As the samples were bulky, they were further held in place with putty. The putty and sample bases were then painted with silver paint. The carbon tape and the silver paint provided a route for the extraneous primary electrons to dissipate away from the sample.

Fig. 5.43 Stucco samples mounted for SEM analysis.

The samples were placed in a vacuum evaporation chamber (Dentron Vacuum DV-502A) and a full vacuum was pulled for about 10 minutes, and a very thin (500Å) layer of carbon was vapor deposited onto the samples. The carbon also served the purpose to draw extraneous primary electrons off the sample so that the secondary electrons emitted from the sample made up the image with minimal noise from the primary electrons from the beam. The samples were analyzed on a scanning electron

microscope (SEM) from Princeton Gamma Tech that can scan up to 300,000 times magnification. These samples, however, were only scanned up to 1000 times magnification.

The test samples were placed on a small platform in the SEM by inserting them through a vacuum seal. This platform could be positioned, turned and tilted so that the sample was viewed at many levels during the test. The electron beam created a 6,000 to 6,500 volt field across a metal filament. This beam scanned the sample at a speed of 1 Hz and while scanning, one CRT showed the actual image produced by the electron emissions, while a second CRT showed the computer enhanced view that constantly averaged 8 separate scans and removed "noise" for a clearer image with better resolution. The images in Figures 5.44 and 5.45 show a comparison at 250 times magnification of the original Tan layer and the newer Gray layer on Tomb #600.

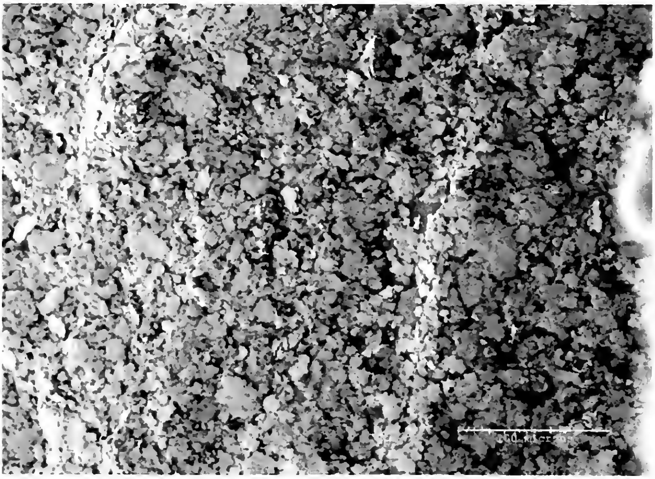


Fig. 5.44 Tomb #600, Tan Stucco Layer, 250 x
Note the porous open nature of the matrix.

The 100 micron scale at the bottom right provides a size perspective for the fines in the matrix.

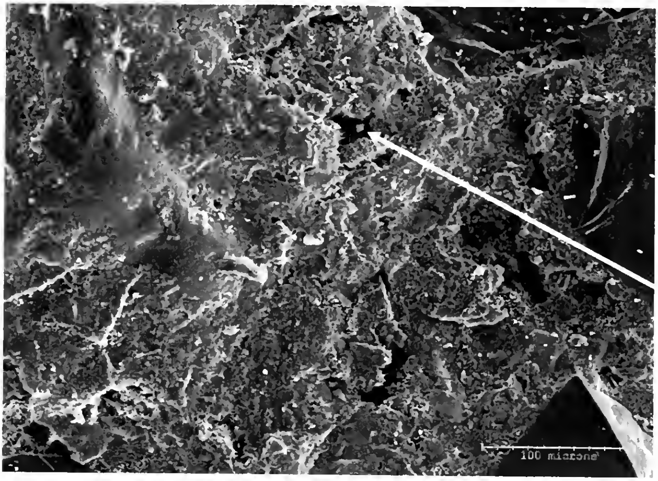


Fig. 5.45 Tomb #600, Gray Stucco Layer, 250 x
The paste matrix is less porous, Expansive acicular (needle-like) crystals can just barely be seen in some of the pores.

The more porous nature of the Tan layer can be seen clearly. In several of the pores of the Gray layer, it is possible to see the expansive needle-like cement crystals developed during hydration. Figure 5.46 shows a different section of the Gray layer with a quartz crystal on the left and a larger pore filled with the acicular (needle-like) crystals from the cement on the right. Small micro-cracks can be seen. Figure 5.47 shows the same pore at 1000 times magnification.

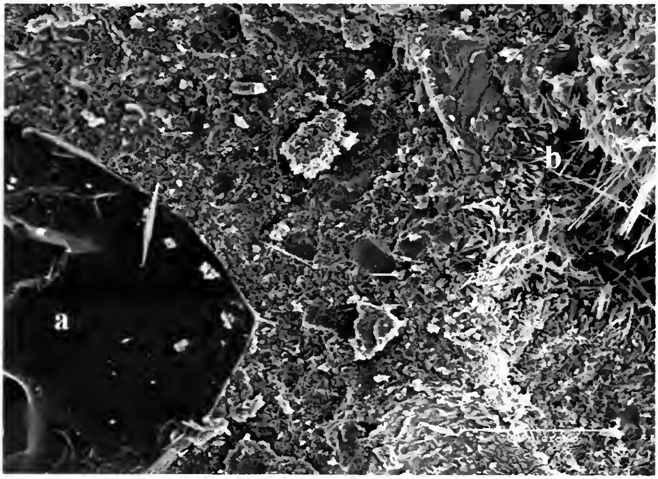


Fig. 5.46 Tomb #600, Gray Stucco Layer, 250 x
A crystal of quartz (a) on the left and an open pore with cement acicular crystals (b) on the right.

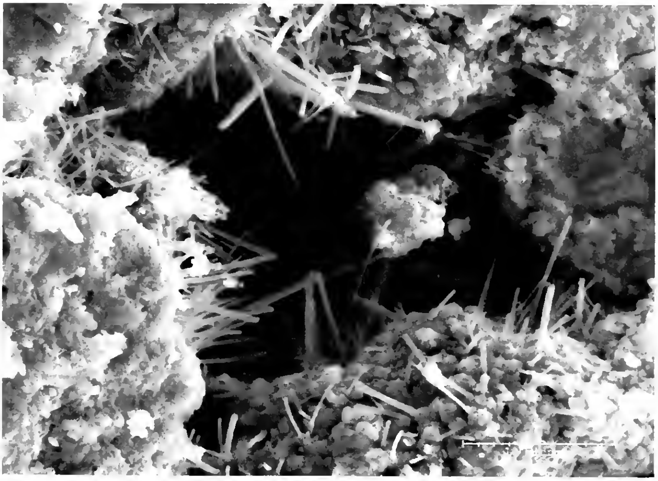


Fig. 5.47 Tomb #600, Gray Stucco Layer, 1000x
The same open pore at higher magnification.

The next series of SEM images focuses on the interface between the Dark Tan and Gray layers of Tomb #200. In the first image at 100 times magnification, micro-cracking at several places along the bond can be seen. The earlier Dark Tan layer is at the top of the image and the newer gray layer is at the bottom. Close to the interface between the two materials, a pore in the Tan layer shows re-crystallized calcite. This can occur if the tan layer is kept wet near its surface by the Gray layer. When wet, the calcite from smaller pores slowly goes into solution and moves towards the surface, re-crystallizing once the water dries out in the larger pore.

Fig. 5.48 Tomb #200, Interface between Dark Tan (top) and Gray (bottom) Stucco Layers, 100x. Note cracks and air spaces at the interface.

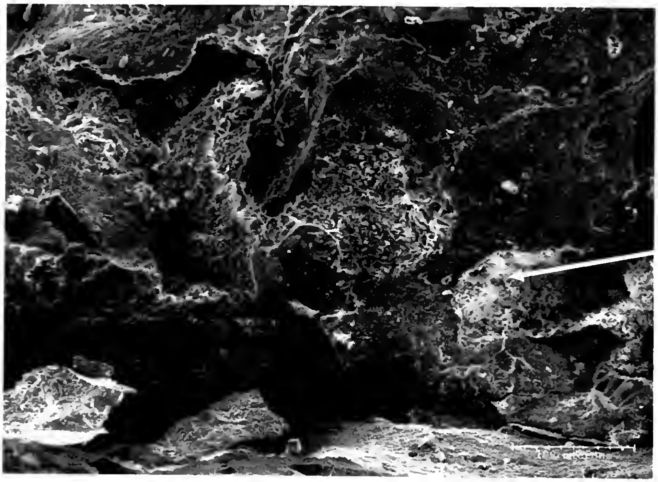


Fig. 5.49 Tomb #200, Interface between Dark Tan (top) and Gray (bottom) Stucco Layers, 250x Note pores with re-crystallized calcite.

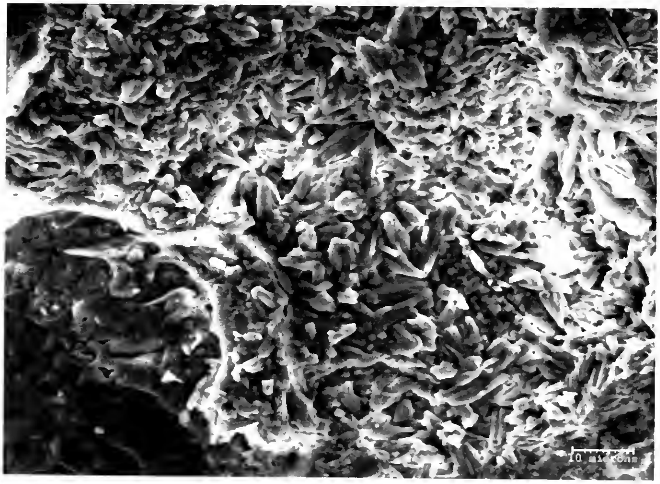


Fig. 5.50 Tomb #200, A highly magnified view of a pore with re-crystallized calcite, characterized by soft, rounded crystals, 1000 x.

5.2.15 X-Ray Diffraction Analysis

X-Ray Diffraction, or XRD, is a useful analytical tool for composition of crystalline materials. The wave-lengths of X-rays are similar in length to the distances between the atoms of a crystalline compound, so the angles of the diffractions of the X-rays can be used to identify the diffraction patterns of different crystalline materials in a sample. The Ragaku Geigerflex Diffractometer at LRSM uses copper for radiation with a known wavelength of 1.54 Å. Graphs are produced that show 2θ, 2 times the incident angle for the X-Rays, or the d-spacing, which is the inter-planar spacing in the crystal. Years of work in XRD have enabled scientists to develop thousands of "pdf's", or powder diffraction files, for known compounds. These "knowns" can be compared to the results from the sample, and identification of specific compounds can be made.

Aggregate and fines from the gravimetric analysis are often analyzed in XRD to identify and characterize the mineralogical phases. Sabbioni, et. al. used XRD to characterize the aggregate fractions, examine the damaged material found in the mortar and "identify tracers of natural pozzolans (feldspathoids; leucite, analcite, nepheline; and pyroxenes; augite and diopside."[142] The problem with XRD is that the phases of interest are usually swamped by an overwhelming presence of calcium carbonate in the binder, and if the binder is not separated from the aggregate, the results will show an

[142] C. Sabbioni, et. al., "Atmospheric Deterioration of Ancient and Modern Hydraulic Mortars." *Atmospheric Environment* 35 (2001):540.

even larger proportion of SiO_2, because of the prevalence of quartz. With XRD, it is also difficult to analyze compounds that make up less than 5% of the whole.[143]

Since most samples contain a few major components and many minor ones, the results from the XRD test can indicate the "possibility" of many exotic compounds and similar appearing scans can be confusing. (See Appendix B for sample scans.) There are computer tools to assist in the search for matches, but even with the highly powered computers, the user must make informed choices on which peaks to analyze and which "possibles" to delete from the analysis. To identify complex mixtures of compounds in cements and many treatments, experience in the science of the materials is critical.

Stucco layers were tested during two sessions. In the first session, those selected were prepared directly from samples of stucco and there was no attempt to reduce the amount of aggregate. During the second session, those tested were the separated fines from the 8 stucco materials of interest. This set of samples included 3 controls; a stucco binder of cured lime putty, one of cured Riverton hydrated hydraulic lime and one made of 1:1 lime putty and Portland cement. These samples were prepared at least 8 years ago, so should have been fully cured.[144]

[143] Elizabeth Goins, "A New Protocol for the Analysis of Historic Cementitious Materials: Interim Report." *International RILEM Workshop on Historic Mortars: Characteristics and Tests, Paisley, Scotland 12th-14th May 1999*, P. Bartos, ed. (Cachan, France: RILEM Publications, 2000): 74.

[144] These samples came from the *Building Materials Library*, samples in the Architectural Conservation Laboratory at the University of Pennsylvania. They were made under the direction of F.G. Matero.

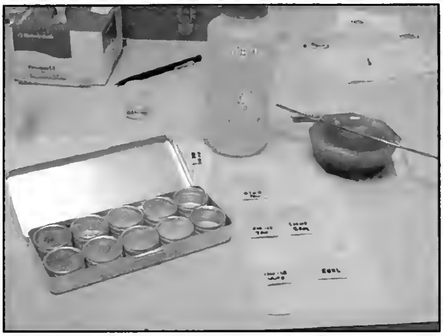


Fig. 5.51 Sample preparation for XRD.

Each sample was finely ground to a powder. The XRD analyzes compounds, not crystal shape, so breaking the larger crystals was required. A slurry with acetone was spread onto the ground portion of a glass slide. The acetone was driven off and the test slide was inserted vertically into the XRD chamber, a Ragaku Geigerflex Diffractometer operating with a horizontal scan. The samples were scanned at 2° per minute in the range of 5° to 60°.

After each scan, the peaks of interest were marked and analyzed by a computer program that compares thousands of pdf's (powder diffraction files) to the sample scan. Each compound could have multiple peaks, so "possibles" were chosen that would match up with all, or a majority, of the peaks that should exist for a given compound.

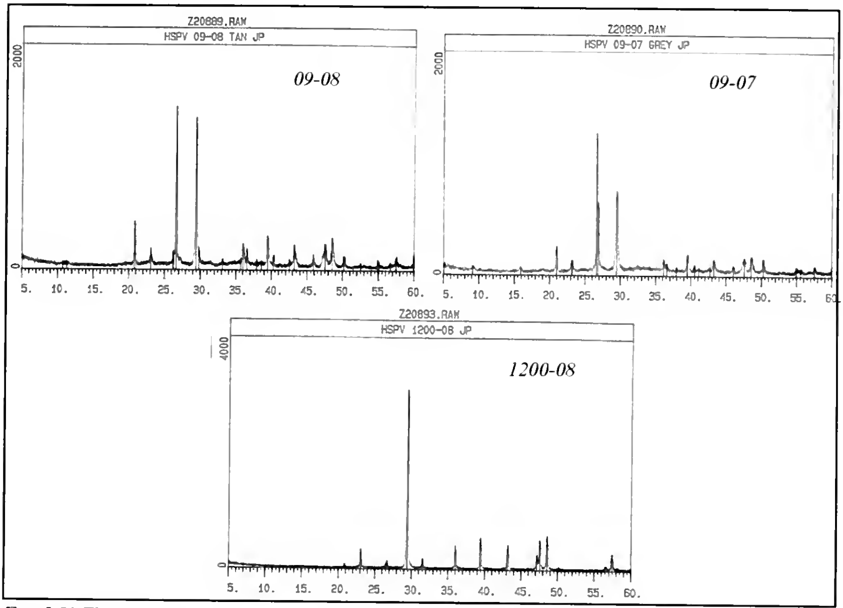


Fig. 5.52 The 2 top scans are for Tomb #09. The Tan layer is on the left and the Gray layer is on the right. The bottom scan is for the White Stucco on Tomb #1200, the early wall vault. The strong peak at around 27 is the main indicator for SiO_2, although several of the smaller peaks also make up the fingerprint. The peak just before 30 is the main peak for $CaCO_3$. Stucco 1200-08 was primarily $CaCO_3$, as expected.

Each of the samples was first calibrated on silicon dioxide or calcium carbonate, as compounds that were known to exist in the sample. The process to determine the remaining components was one of elimination. As each component was chosen as being part of the scan, the peaks were eliminated and the program reported the remaining portion of the scan to be identified. While not a quantitative method of analysis, these reported percentages gave an indication of the ratio of the different components.

The table below shows the compounds identified for the samples tested, and the percent of the scan attributed to that compound. Calcium carbonate includes indications for both calcite and aragonite, two different crystalline forms of $CaCO_3$. The category "Silicates" includes gismondine ($CaAl_2Si_2O_8 \cdot 4H_2O$), larnite ($Ca_2SiO_4$), ettringite ($Ca_6Al_{12}(SO_4)_3(OH)_{12} \cdot 26H_2O$) and andradite ($Ca_3Fe_2(SiO_4)_3$, or calcium iron silicate hydroxide). Samples from the first series of tests are marked with "++" for major components, and "+" for a small component.

Table 7

XRD Results of Stucco Samples

Sample	Quartz	$CaCO_3$	Silicates	CaO, CaOH
200-03, White	+	++		
200-01, Gray	++	++		
09-08, Tan	42%	45.3%	2	4%
09-07, Gray	56%	30%	5	
600-02, Tan	31%	64.5%		
600-05, Gray	51%	33%	4%	
1200-01, White	4%	93%		
Lime Putty Control	6	49%	3	36%
Hydraulic Lime		79%	13%	
1Lime:1Portland	29%	32.2%	32.2%	

During the first test run of sample 09-07, Gray, ettringite was detected. It was not detected in the second scan of the fines. It was concluded that since ettringite is a damage result, generally occurring in cements exposed to moisture driven sulfate

damage, the ettringite most likely was attached to larger particles of binder and aggregate that were sieved out of the second sample. In the first test, samples of the stucco matrix and aggregate were finely ground, leaving the ettringite in the powder form used for XRD analysis.

In the sample chart above, the two samples from the White stucco group, 200-03 and 1200-01 are primarily calcium carbonate with a small fraction of quartz. The 09-08, Tan contains silicates and calcium oxide, good indicators that this stucco layer may contain hydraulic lime. The hydraulic lime control contains larnite (Ca_2SiO_4), a dicalcium silicate expected to be found in hydraulic lime, but not in cement. The ettringite in 09-07 and the calcium silicate (Ca_3SiO_5) found in the 1-Lime:1-PC control are tricalcium silicates expected to be found in cement. The Gray layer for Tomb #600 did not show cement components, however, they may have been smaller than 5%. Only 88% of the peaks were accounted for in the analysis, so the remaining mixture could have been multiple C_3S components, each less than 5%. The small amounts of unresolved peaks in each of the samples are those that would contain the small impurities of iron, and other colorful minerals that cause the binders to differ from each other in color.

5.2.16 Thermal Gravimetry, Differential Thermal Analysis

Since the use of thermal analysis is so prevalent in the study of cement chemistry, there are good reasons to exploit this tool for the study of lime and hydraulic lime mortars. TGA/DTA can be used to examine crystalline transitions (endothermic and exothermic) and thermal transformations, such as dehydration, dehydroxylation, oxidation and decomposition. However, there are no existing standards for historic materials at this time. Paama, et. al. concluded: "The interpretation of the thermal decomposition of mortars is generally difficult because of a great variety of components used, which depends on country, source of binding and inert materials and on the age of buildings."[145] Charola and Henriques said: "it is clear that the identification of the hydraulic phases formed, ... is very difficult. This can be attributed to the variability of composition of pozzolanic materials, the conditions of the pozzolans-lime-water reaction than the rapid loss of water during the setting of the mortar resulting in very small sized reaction products. This compounds the already difficult characterization given their low concentration in lime mortar."[146]

The group that has recently published the most research of historic materials utilizing thermal analysis is led by Moropoulou, and each article includes contributing

[145] Lilli Paama, et al., "Thermal and Infrared Spectroscopic Characterization of Historical Mortars." *Thermochimica Acta* 320 (1998): 127.

[146] A. Elena Charola and Fernando M.A. Henriques. "Hydraulicity in Lime Mortars Revisited." *International RILEM Workshop on Historic Mortars: Characteristics and Tests, Paisley, Scotland 12th-14th May 1999.* (Cachan, France: RILEM Publications, 2000): 101.

researchers from a wide variety of European research institutes. In their article on the characterization of ancient mortars, they describe key identification peaks that separate lime from hydraulic lime from cement mortars and state: "Generally, the CO_2 bound to carbonates and the water bound to hydraulic components (in weight loss %) discern two groups of mortars, the typical lime and the hydraulic, respectively."[147]

Thermal analysis run in the TGA, Thermal Gravimetric Analysis mode measures the weight loss of the sample as the temperature is raised at a consistent rate per time. In rare cases, there can be a weight gain, as in the example of heating the sample in an oxygen atmosphere. A weight loss (gain) curve is plotted as weight over time. An abrupt change in the slope indicates a phase change.

This same unit at LSRM also analyzes samples in the DTA, Differential Thermal Analysis mode, where the sample cup and an identical reference cup have small thermocouples attached. During the test, the temperature by voltage difference is measured. If there were no differences, the line would be flat. Peaks above the line indicate an exothermic phase change and peaks that dip below the line show an endothermic change. The area of the portion of the curve that deviates from the flat line can be calculated for a quantitative method to analyze the component.

[147] A. Moropoulou et. al. "Characterization of Ancient, Byzantine and Later Historic Mortars by Thermal and X-Ray Diffraction Techniques." *Thermochimica Acta* 269/270 (1995): 781.

The fines from 4 samples representing the Tan and Gray layers of Tombs # 9 and 600 and 3 controls (stucco with binders of hydrated lime, lime putty and 1 lime to 1 Portland cement) were finely ground and 15 mg were used for each test. The tests were run in an argon atmosphere at 20°C per minute to 1000°C. The resultant curves do not match the findings of Moropoulou, et. al., even for the one sample that was run in air to attempt to match their conditions. However, the results of the samples are informative when compared to the control samples.

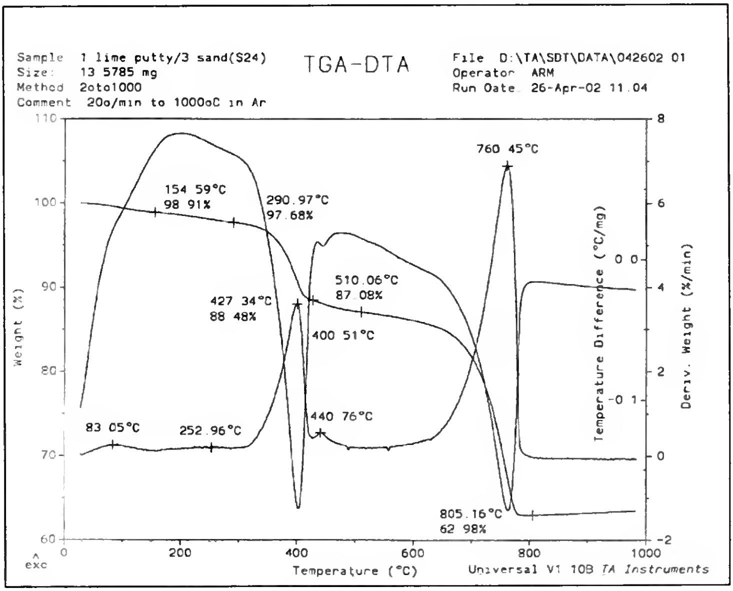


Fig. 5.53 The lime putty control sample.

The Moropoulou, et. al. work indicated that in a lime based mortar, no strong reaction should be expected except the release of chemically bound water around 800°C, and

that the release of bound clays in hydraulic lime and cement would take place around 200-250°C. All samples in this research showed the gradual release of absorbed water before reaching 100°C and showed the release of bound water in the calcium carbonate between 720 and 760°C. The lime putty control experienced a strong exothermic reaction around 400°C, a reaction McGhie identified as an indication of $CaCO_3$ in the sample. The hydraulic lime also showed slight indication of a reaction before 400°C and the 1 lime to 1 Portland cement experienced a strong reaction in the same region.

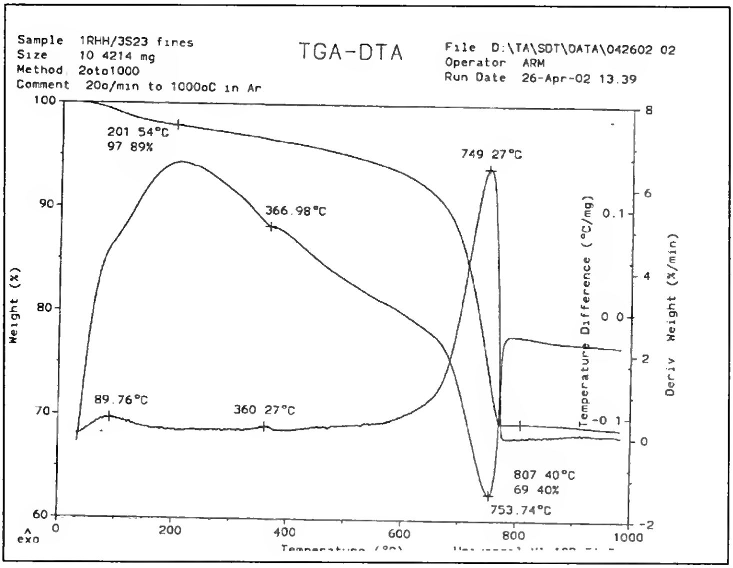


Fig. 5.54 The Riverton hydrated hydraulic lime control.

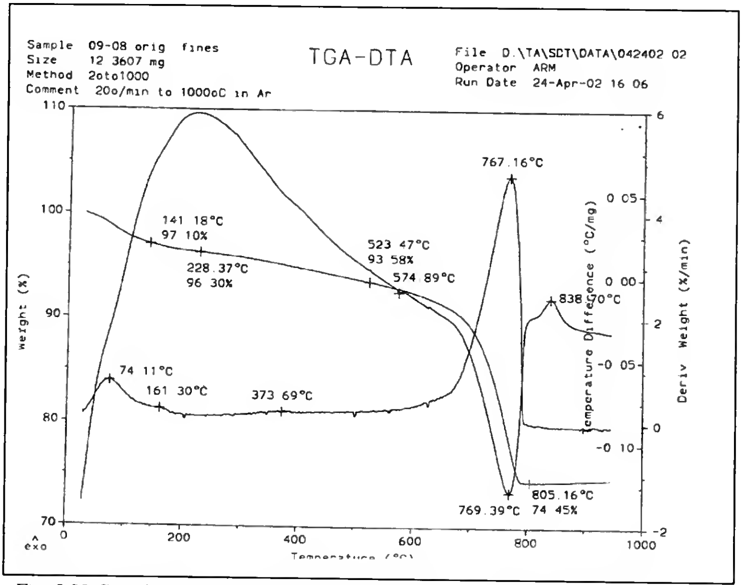


Fig. 5.55 Sample 09-08, from the original Tan layer. This curve is similar to the hydraulic lime curve.

When the Tan layers of Tomb #09 and 600 were compared to the controls, they both experienced exothermic reactions around 840°C, an area in which none of the controls had reactions. They both experienced only the slightest reaction around 370°C and appear most like the curves seen for the hydraulic lime control. The graph for the Gray layer sample for Tomb 09 is inconclusive, as it showed no strong peaks of reaction to indicate that it was a cement or a hydraulic lime. The sample of 600-Gray released a large quantity of bound water at 90°C, probably indicating a hydrated compound, such as one of the hydrated silicates. An acid digested sample of 600-Gray had been tested

earlier and the curve showed the same release, without any $CaCO_3$ reactions around 400 or 800°C, since the $CaCO_3$ would have all been removed.

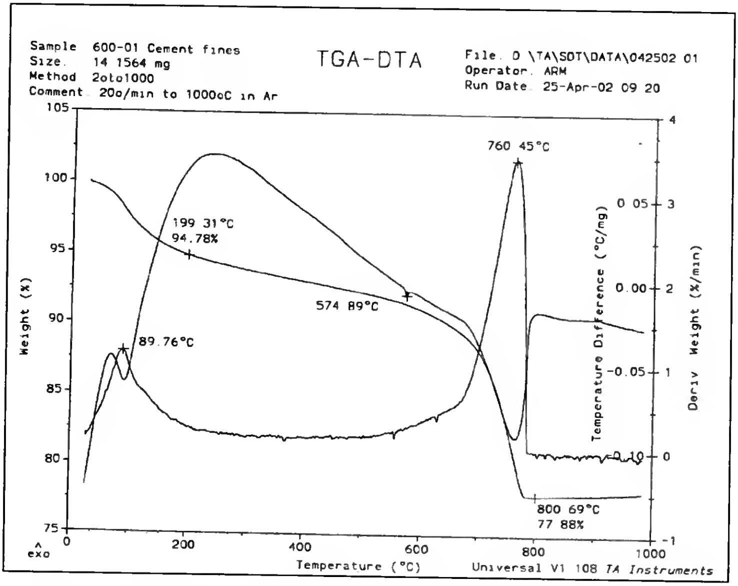


Fig. 5.56 The 600 Gray layer shows an exothermic reaction before 100°C, which does not show on the 1Lime:1Portland control. (See Appendix B for all scans.).

Without a stronger library of historic samples and related TGA-DTA curves, it is difficult to make definitive statements about what can be proven from these graphs. The most obvious conclusion is that the original Tan layers appear to have hydraulic components and that the cement layers differed in their mix ratios of cement, lime and other additives.

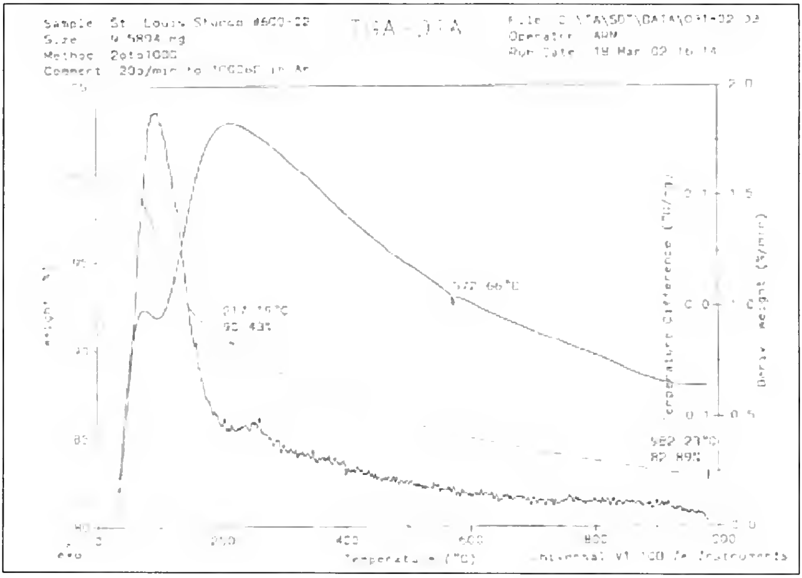


Fig. 5.57 Digested fines from 600-Gray layer. No $CaCO_3$ reactions show around 400 or 760°C. The release of bound water around 100°C represents the presence of a hydrated compound. The alpha to beta transition of quartz can be seen around 573°C.

5.2.17 Laboratory Analysis – Observations and Conclusions

The phased approach of analytical testing conducted for this research has effectively reduced a very large sample set of 700 composite tomb structures of mortar, stucco and brick into a manageable number of groups for which we can state several conclusions.

The mortar is the weakest material and the material most prone to dissolve. During sampling, it was difficult to find samples that did not already show some advanced level of degradation. Under visual characterization the mortar samples were soft, fragile and easy to break. In the total immersion test the mortar samples absorbed 22% of their weight in water, and all exhibited some level of dissolution. The samples were too weak to subject to the WVT, capillary absorption or drying rate tests that were used for stucco and brick. Gravimetric analysis showed the mortars to have a significantly higher amount of fines and visually, the reddish fines appeared to be of clay and silt. A few of the mortar samples (8) did not fully digest with HCl, and the coating which did not react to HCL in later testing, warrants further investigation.

In test of the 4 stucco color groups, the order of absorption capability, porosity, capillary absorptive pull and drying ability generally progressed in the same order as the aggressiveness of acid digestion. The most heavily lime based group (White) was the most absorptive and most easily digested, and the cement based (Gray) group the least. The exception was in the water vapor transmission results, where the White group's high absorptive capability actually seemed to slow down its ability to transmit moisture in the vapor form.

The aggregate in the stucco groups were all well-graded, and the degree of sub-angularity increased from White to Tan to Dark Tan to Gray, an indication that more

pre-mixed, non-local hydraulic components were added. Both XRD and TGA-DTA testing also indicated the probable presence of hydraulic lime (natural cement) in the early stuccos. SEM was useful to provide visual proof of the damage at the interface between materials and to show the expansive nature of the development of acicular (needle-like) cement damage product crystals.

Visual characterization of brick samples confirmed that the brick at St. Louis Cemetery No. 1 is almost exclusively the local hand-made River or Lake brick. Both are soft and porous with the River brick being the softest, and exhibiting the most dissolution during the total immersion test. The brick types are both quite absorptive with strong initial capillary pull, and both exhibit a high capability to transmit moisture. Where the bricks have been exposed, there is evidence of weathering. However, loss of the outer layers of brick by weathering, salt or freeze-thaw damage is not the problem at this site. Tests for salt presence found almost no salt evidence at the brick interface. Instead, the structural problem exhibited by the brick construction is caused by movement of brick slipping through areas of mortar loss. Once the original structure moves, the shifts in load and weight create shear tension, which leads to cracking throughout the structure.

6.0 TOMB DECAY MODELS & SCENARIOS

6.1 Tomb Decay Mechanisms Confirmed

Based on the results from this research, many of the deterioration results seen in the masonry at St. Louis Cemetery No. 1 can be explained by the decay mechanisms discussed in Chapter 4. The local environment and site conditions provide considerable quantities of water from driven rain, high levels of ground moisture and condensation from the high relative humidity. The brick, mortar and stucco materials were all porous. Based on composition and porosity, they absorbed and de-sorbed moisture at different rates. Table 8 contains the summary data for all moisture related tests made of stucco discs and brick cubes, and the M_{SAT} average from the total immersion test of the mortar samples. These results will be referenced in the following discussion.

Fig. 6.1
Tomb # 135

Fig 6.2
Tomb # 1200
(wall vault)

Table 8
Summary Data – Sample Categories Response to Moisture

Category	No.	Density g/cm^3	WVT $(g/day*m^2)$	Cap. Absorp Coeff $g/cm^2\ sec^{0.5}$	Imbibition Cap %	Est. % Porosity	Critical Moisture Content	Critical Moisture Content %
Bricks								
All Brick	31	1.70	468.72	0.0352	18.81%	30.50%	0.1436	45.43%
Imported (Bare)	1	1.95						
All Lake Brick	16	1.73	436.44	0.0312	16.91%	28.25%	0.1721	57.51%
All River Brick	14	1.66	519.61	0.0418	21.67%	33.95%	0.1160	32.12%
Bare Lake	6	1.70	601.52	0.0341	18.18%	28.68%	0.1532	48.51%
Lake w/ Stucco	10	1.75	326.39	0.0294	16.15%	28.00%	0.1835	62.91%
Bare River	6	1.60	711.61	0.0471	23.93%	36.22%	0.0313	7.60%
River w/Stucco	8	1.70	375.60	0.0378	19.97%	32.25%	0.1795	50.51%
Stucco								
All Stucco	35	0.44	116.70	0.0023	11.52	19.90%	0.0311	61.93%
White xSF	3	0.42	123.08	0.0052	23.02	34.18%	0.0215	33.68%
Tan xSF	7	0.45	174.66	0.0025	12.21	21.29%	0.0309	53.86%
DkTan xSF	5	0.43	136.61	0.0024	11.73	19.62%	0.0272	51.72%
Gray xSF	5	0.45	80.37	0.0019	9.04	15.23%	0.0364	82.57%
WhiteGray xSF	3	0.41	115.26	0.0023	11.05	21.79%	0.0380	80.06%
Combinations xSF	5	0.44	99.20	0.0016	9.93	17.52%	0.0298	64.96%
Original Stucco xSF	15	0.43	145.76	0.0028	14.06	23.02%	0.0292	50.58%
New & Combos xSF	13	0.44	95.66	0.0019	9.85	17.63%	0.0342	75.22%
Mortar	22				25.36			

6.1.1 Brick

The most powerful moisture absorber is the brick wall. The River bricks can hold about 24% of their weight in water through capillary absorption. Their capillary absorption coefficient, indicators of the capillary, or sucking power, is the highest of all materials tested at 0.0471 g/cm^2 $sec^{0.5}$. The Lake bricks are also quite capable of absorbing large quantities of water and averaged 18.2% imbibition capacity with a capillary absorption coefficient of 0.0341 g/cm^2 $sec^{0.5}$. Even if these brick walls were totally covered in impervious outer coatings, the high ground water in St. Louis Cemetery No. 1 would be the major source for capillary absorption. Water at the base, high capillary absorption coefficients and small, variable capillaries in the handmade bricks set up a condition that allow the brick wall to fully load with water to the imbibition capacity at numerous times throughout the year.

When tested in an exposed (bare) condition, the River bricks have the lowest critical moisture content and can easily de-sorb most of the moisture through evaporation to the dryer air once humidity levels fell. Many have good rates of evaporation until the last 10% of moisture remains. When tested with a layer of stucco still attached, the curves became more complicated and evaporation slowed down when about 50% of the moisture had evaporated. In comparison, the Lake bricks had good rates of evaporation for the first 55% of moisture before slowing down. With a layer of stucco

still attached, they slowed down sooner, after only about 38% of the moisture was gone. These results illustrate how the difference in porosity between brick types affects the basic properties of moisture movement and how easy it is to impede a material's ability to dry through evaporation, once an outer coating is applied.

In spite of the reduction in evaporation, the traditional practice of coating the bricks was not the wrong approach, based on the soft nature of the bricks and the high levels of available moisture. By remaining covered, the bricks remain in a damp condition, are protected from wind abrasion and thermal cycling, do not cycle through wet and dry phases and do not experience dissolution and re-crystallization of salts. Since there is seldom frost in New Orleans, the bricks also do not normally experience damage from crystallization of the absorbed water. Minimal salt damage had been seen in the historic materials, and the tested brick solutions showed negligible salt presence. These factors are key explanations to how well the interior bricks have performed at St. Louis Cemetery No. 1 when protected.

6.1.2 Mortar

The mortar joints are capable of holding the same moisture content on average as held by the bricks. The samples tested in this research had an average moisture content at saturation of over 25%. In all tombs tested, the tomb mortar absorbed greater amounts

and at a greater initial slope than did the stucco layers from the tomb. The mortar was not strong enough to hold up through the capillary absorption and drying rate tests that were conducted on the bricks and stucco. However, based on the results of the mortar analysis, it is not expected that the mortar would have a low critical moisture content value because of the high proportion of water reactive clays and silt. Since there is no atmospheric exposure, the mortar plays no role in moving moisture away from the interior system. Since the mortar is surrounded by wet bricks, it can remain at imbibition capacity as long as the bricks are wet. The mortar tested was weak, the aggregate was heavily skewed to the smallest fractions and the fines proportion was more than double that of any of the stucco groups. The fines appeared to contain a large proportion of silt and clay. This would not create a problem if the tomb surfaces were fully protected by a tight, permeable stucco skin to allow the mortar to dry slowly without any new incursions of external moisture.

The areas of mortar decay can be described by the following mechanism. In the environment of 100% humidity, any extra moisture that comes into the system soaks around the mortar in liquid form, and the slightly acidic water sets up dissolving reactions with the carbonates in the crushed shell and the weaker silicates. The raw clay particles are very absorbent, holding water between the many plates that defines the clay structure. The clay expands, creating internal stresses in the mortar paste, and eventually this stress breaks down the mortar. As the mortar breaks down, the

adhesion to the brick and stucco layers also breaks, creating interior channels for non-uniform liquid water transport. Open gaps develop between bricks and this loss of support allows them to slip out of position. Over time, this slippage causes stucco layers to crack and/or built up internal shear stresses that led to structural damage, such as corner failures, lost bricks and severe telescoping.

6.1.3 Stucco

There were many bulk stucco mixes used at St. Louis Cemetery No. 1. Five loosely defined groups based on color and initial total immersion results were used for characterization in this research. However, in every test, exceptions within the group stood out, and one major conclusion that can be made is that there were no one or two accepted stucco mixes used in the building of these tombs. A few remnants existed of the earliest practice of shell-lime stucco in areas of the wall vaults and on a few tombs. Most of the early stucco appears to be the sandy tan colored stucco, the Tan group, and results from mortar analysis, XRD and TGA indicated that many of these may contain hydraulic components. The darker, less porous Dark Tan group also showed indications of mixtures with hydraulic lime (natural cements). The mid-twentieth century additions of cement layers, Gray group, on top of original materials have not performed well in terms of overall protection.

With the exception of the White group, the stucco materials do not approach the absorption behavior of the interior bricks and mortar. The most important role of the stucco layer is to protect the interior materials from exterior salts and pollutants and to ensure that no water in liquid form is allowed access through the walls. This research would suggest that protection of the mortar joints is an even more important objective, than is protection of the brick, given the high clay content of the mortars.

Based on the results, all but the White group of stucco worked well to resist easy saturation from a quick rain storm or period of high humidity, holding from 9 to 12.2% of their weight in moisture. Added surface finish, if in good condition, further inhibits surface wetting of the stucco layer. Although tombs with impermeable finishes have severely reduced water vapor transmission, the tombs with a permeable lime-based surface finish had comparable WVT rates.

The White group is capable of holding the most moisture at almost the same levels as found for brick and mortar. It is also the most willing to give up moisture with a critical moisture content of only 34% and would be capable of drying quickly. If moisture capacity and drying ability alone dictated decay, the White group stucco would be most in balance with the interior brick and mortar. However, it also is the softest material and breaks easily with internal movement of the brick. Further, it is the most acid soluble, and is the most readily attacked by acidic rain and pollution.

The Tan and Dark Tan groups are more willing to release the moisture, given a dry sweep of air over the surface. The capillary absorption coefficients are not high enough for these materials to pull moisture from the brick by capillary action. The structure will instead dry through the slower diffusion process, with water molecules leaving the region of many, to move to a region of few, the air-dried layer of stucco. The critical moisture content is around 50%, meaning half of the water de-sorbs rapidly and the remaining half needs more energy, such as good air ventilation or heat. These conditions can be found at St. Louis Cemetery No. 1.

The Gray group absorbs less than the earlier Tan and Dark Tan group, but is very resistant to drying, with a critical moisture content percent at over 80%. When this material is layered over a Tan or Dark Tan group stucco, it effectively inhibits the original layer's ability to dry through evaporation and holds the composite system in a static damp, lowered strength condition. The water vapor transmission rate is also the lowest of the stucco groups, which adds to the resistance the cement exhibits to allow interior moisture to diffuse to the exterior. Several of the stucco discs showed salt evidence during the absorption and drying cycles and the salt presence tests were most positive with the samples from the Gray group.

While it was stated above that it might actually be preferable that the soft interior bricks are not able to fully dry after each cycle of ground water capillary absorption, the failure of the rest of the system is not acceptable. The layers of stucco are only 1 to 4 cm thick, and when filled with variable levels of moisture, the forces of gravity, thermal expansion and hygric expansion all act at different rates depending on the material composition and the amount of water. Stresses build up in the thin layers, eventually leading to micro-cracks. Micro-cracks act very effectively as capillary tubes, pulling in more moisture which sets up greater stress and a full crack occurs. The full crack then directs water, pollutants, biological spores and seeds into the interior to cause unit masonry displacement and the breaking down of materials through the many processes discussed in Chapter 3, Tomb Decay Mechanisms.

6.2 Tomb Combinations Illustrated

The values in Table 8 are more meaningful when seen in several specific tombs where all the components interact. The figures in each material will always show the imbibition capacity, or M_{SAT} from the initial total immersion test, and if there appears a number below, it will be the critical moisture content percent. The data for additional tomb combinations can be viewed in Appendix C, Summary Data.

Tomb #09 can be used to illustrate both the simple composite system of only one stucco covering and the complex composite system of multiple stucco layers. Tomb #09 is a poor condition platform tomb with a first visible date of 1822. The original stucco is Tan and the brick is River. In this tomb, the mortar is surprisingly low in moisture absorption, but is still higher than is the adjacent stucco layer.

Fig. 6.3 Tomb #09, Platform, First Date – 1822.

Fig. 6.4 Tan and Gray stucco layers evident.

Before the tomb was repaired with a heavy coat of concrete, the wetting and drying processes would progress as seen in Figure 6.5. Most of the dampness would enter the tomb through rising damp as the bricks absorbed 24.5% of their weight. The mortar also had a high initial slope of water absorption and would be able to fill to its capacity of 11.36% when surrounded by damp bricks. The stucco, exposed to dry air, would initiate the drying process and through diffusion, water molecules would slowly move from areas of higher concentrations to lower concentrations in the dry stucco, and then out into the exterior dry air. The mortar joint would dry out under most conditions so

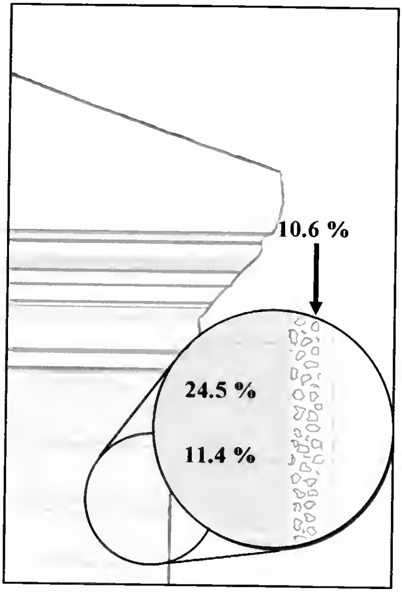


Fig. 6.5 Simple composite system, one stucco layer and surface finish. Tomb #09 data added.

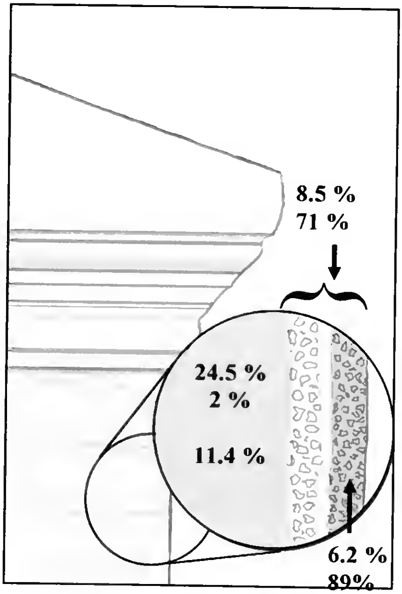


Fig. 6.6 Complex composite system, multiple stucco layers. Tomb #09 data added.

that it did not remain in a wet, dissolving state. The bricks would often remain damp and would not frequently cycle between the wet and dry states.

When the layer of concrete was added to the tomb, the moisture movement dynamics radically changed. The combination of Tan-Gray stucco had an imbibition capacity of 8.49% as opposed to the M_{SAT} value of 10.65% for the Tan layer alone. The Gray layer alone had an imbibition capacity of only 6.25%. If the Gray layer also had a low critical moisture content, it would be able to drive the drying process and the low imbibition absorption value could be a positive factor. However, the critical moisture

content % of 89% means that once the Gray layer lost only 11% of its moisture, the process stopped, leaving the interior materials damp with the weak mortar placed most at risk. The resultant damage has been observed in many tombs when the damaged gray cement layers are removed from the earlier brick and stucco beneath.

The difference in hygric expansion between the Gray and Tan layers are generally not enough to cause the major damage. Instead, the salt damage created by the Gray layer and the weight of the water held in both layers pulled down by gravity, compounded by the internal stresses created by the dissolving mortar joints and moving bricks, create the first micro-cracks. These capillary cracks directed more water in liquid phase into the interior and creates great non-uniformities in moisture absorption throughout the composite system, which leads to much larger cracks.

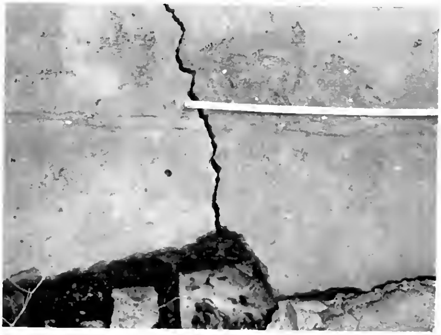


Fig. 6.7 Structural crack in Tomb #09 caused by too much strength in the outer layer of stucco.

The strength of the outer concrete is such that it holds stresses in compression until they become too great, and then react through a major failure. The adhesion of the Gray layer causes the weakest materials to break, rather than the Gray layer bond.

Fig. 6.8 The back of Tomb #600 covered in cement stucco. The front of the tomb is patched. Note the loss of the cornice with the new cement.

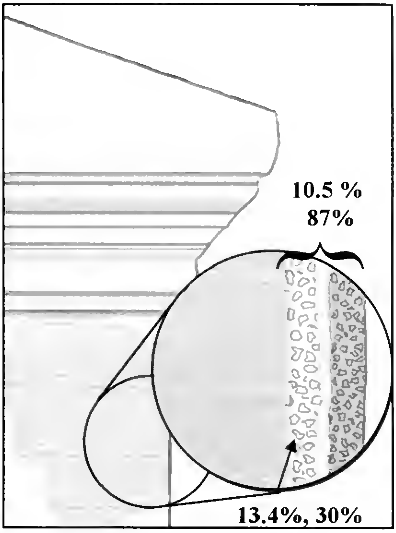


Fig. 6.9 Complex composite system, multiple stucco layers. Tomb #600 data added.

For Tomb #600, no bricks were tested. This tomb has been patched in cement stucco and the back of the tomb has been completely recovered in cement. A dripping water faucet adds an uneven source for rising damp. The Tan layer has an imbibition capacity at 13.44% vs. the composite Tan-Gray layer at 10.93%, and the drying process would slow down at 33% in the Tan layer alone vs. at 87% in the combination of layers. The Gray layer will inhibit the drying process of the interior materials.

At the patch boundaries, the cement layer will keep the seam wet, allowing more movement at the seam caused by recyrstallized calcite, gravity and hygric expansion.

There will also be more dissolution of materials, and more development and accumulation of expansive calcium silicate salts like ettringite at the Gray layer's edge. Throughout the site, there were many examples of deterioration around the edges of cement patches. Since the strongest material transfers stress to the weakest, the damage was usually found in the weaker historical materials of stucco and brick.

Fig. 6.10 Tomb #558 was originally covered in Tan stucco and has been patched with Gray (cement). When the Gray layer failed, it cracked at the interface with the original stucco, forcing new cracks into that layer, and tore off the brick faces wherever it was directly adhered. In some cases the released stress caused the pulling out of the entire brick. The missing bricks in the image above were found on the ground about the tomb with the cement stucco still firmly attached.

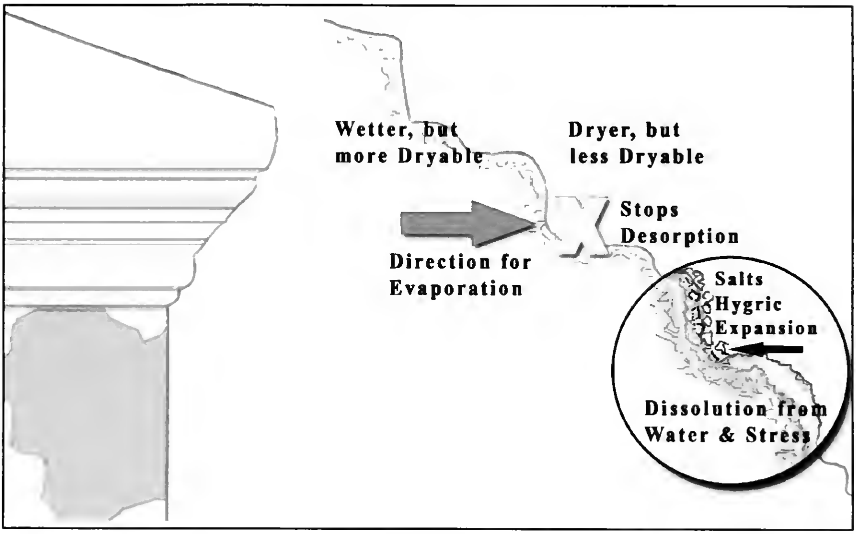


Fig. 6.11 Decay mechanism at edge of incompatible patch.

6.3 Tomb Decay Scenarios

Based on the *Survey*, field observations and material analysis results from this research, coupled with historical information on original construction and cultural practices, a set of seven scenarios have been developed that highlight the primary decay mechanisms that have created the current conditions at St. Louis Cemetery No. 1. Each scenario includes multiple images that show how the combination of material, design, methods and the environment has created specific conditions. The scenarios were developed to

educate and open dialogues with tomb owners, managers and restoration volunteers on the following:

- How do the decay mechanisms work?
- How have current conditions developed?
- How critical is each of the problems?
- How can the decay mechanisms be arrested, or slowed?
- How should current conditions be stabilized?
- How should restored tombs be maintained?

6.3.1 The Well-Maintained Tomb

In the well-maintained tomb, the tomb owners regularly applied lime wash to protect the stucco skin. When small cracks began to develop, they were noticed during the frequent attention and were repaired. Eventually, as cracks began to grow larger, the decision would have been made to repair or re-stucco areas of the tomb. The family caretakers would notice small changes in the tomb as moisture driven movement and weathering occurred. These issues would be repaired or stabilized during the regular maintenance work before real problems threatened the tomb. Highly vulnerable building elements such as roofs may have been repaired more often. Roof stucco repairs over intact original brickwork is a common condition at the site.

Fig. 6.12 The stucco skin on Tomb #230 has been well maintained. A modern finish coats the tomb, but has been applied over a well-prepared surface and shows no peeling or flaking. Some biological growth and higher vegetation is beginning to take hold and should be removed before problems start. A high integrity tomb on a marble precinct, surrounded by a path of grass. Studio photograph, March 2001.

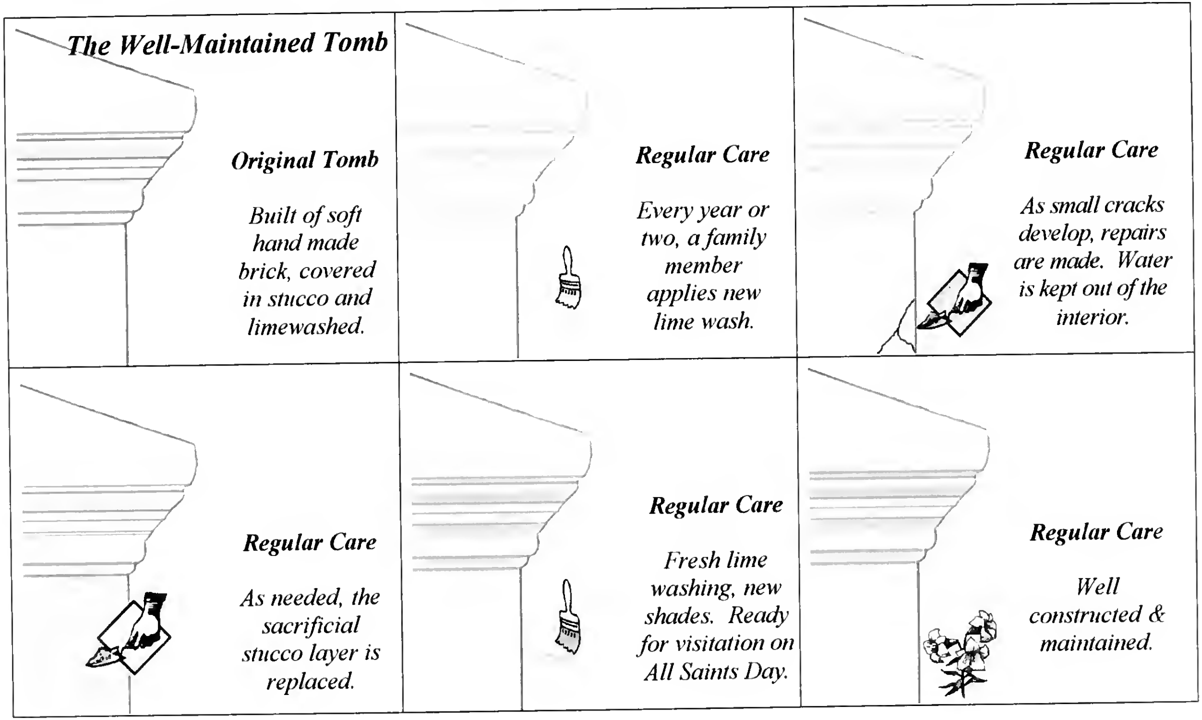


Fig. 6.13 Scenario: The well-maintained tomb.

6.3.2 Neglected Surface Finishes

The application of lime washes served to reduce the surface area of the stucco and thus reduce initial water absorption, particularly in conditions of falling damp. The surface finish also provided a smoother surface less inviting to biological growth and was temporarily biocidal, as well. When surface finishes were allowed to deteriorate, breaches would develop in the layer, allowing water entry, dirt accumulation and biological growth. Such breaches became weak points when a later application of surface finish was made, leading to thick, uneven build-up of poorly attached material on the stucco surface. Over time, micro-cracks developed in these areas. The micro-cracks were of a size that enhanced capillary absorption into the interior stucco material. The micro-cracks expanded to larger cracks where biological growth took root. With time, neglected surface finishes resulted in a dirty tomb with uneven remnants of finish and aggressive biological growth and set up the conditions for further deterioration through moisture driven cracking mechanisms.

Fig. 6.14 Neglected surface finishes, cracks and biological growth evident. Studio photograph, March 2001.

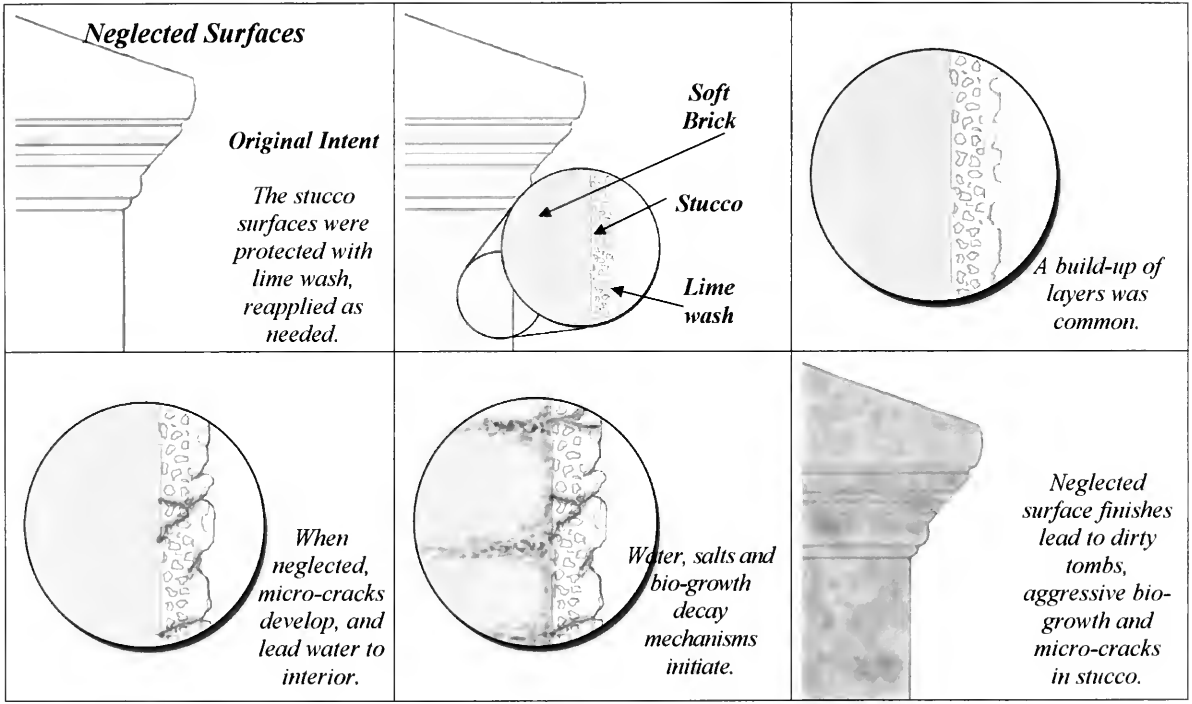


Fig. 6.15 Scenario: Neglecting surfaces.

6.3.3 Deferred Repairs

All built structures require maintenance. If that maintenance is constantly deferred, opportunities are missed to fix small problems before they grow into larger damage and compromise the tomb structure. Cracks allow moisture an uneven access to the tomb materials. This leads to broken adhesive bonds between stucco, brick and mortar, all of which can create more cracking and detachment. Once water is directed through a crack into a mortar joint, dissolution of mortar can take place, loosening the brick. Typically, damage is first evident at the top of the tomb, where falling damp has the greatest impact and the bricks have the least weight above to hold them in place. Movements of brick lead to wall instability and more structural cracking and the deterioration cycles out of control until the tomb becomes a ruin.

Fig. 6.16 Tomb #39, an example of years of deferred repairs. Periodic patching with cement and modern paint over the failing structure has provided no benefit.

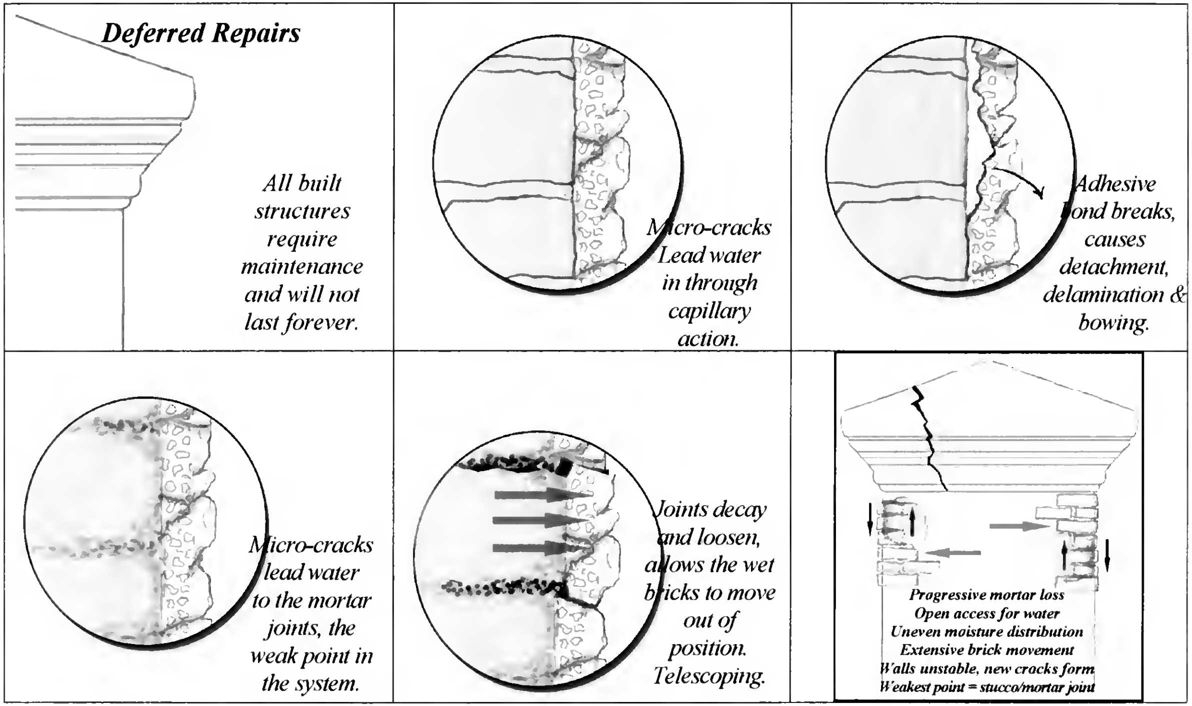


Fig. 6.17 Scenario: Deferred repairs.

6.3.4 The Unwelcome "Garden"

Section 3.4.3 discusses the cycle of biological growth from simple to complex organisms which are illustrated in this scenario. The high heat, humidity and rainfall in New Orleans create a long growing season. A solid stucco skin is the best defense against the invasion of higher vegetation and the structural damage that plants and root systems create. Once cracks are allowed to develop, growth and destruction will begin. Root systems can progress deep into a tomb seeking nutrients from the clay-lime rich mortar, resulting in broken mortar to brick adhesive bonds and more disruption of the brick structural wall. When plants are killed with chemicals after root systems have already burrowed into the masonry, the removal of the dead plant leaves new channels for water and more biological growth. The chemicals can also be harmful to the masonry elements or add new soluble salts into the groundwater.

Fig. 6.18 Bio-film and moss have progressed to high level vegetation. Ferns are growing in the roof cracks and will soon cause major destruction. Studio photograph, March 2001.

Fig. 6.19 The stucco has been completely breached. Mortar has been replaced by moss. Studio photograph, March 2001.

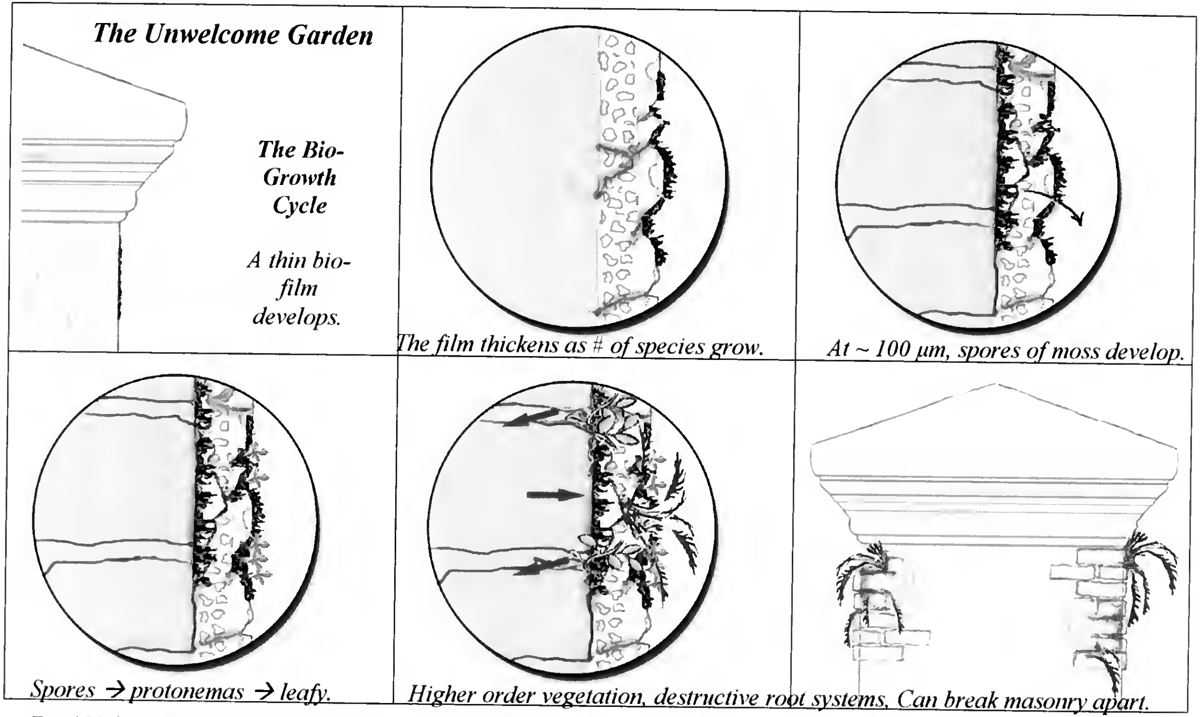


Fig. 6.20 Scenario: The unwelcome garden..

6.3.5 Incompatible Surface Finishes

Incompatible surface finishes fail because of failed adhesion. Adhesion relies on mechanical means to lock into a porous surface or a chemical attraction between surface and finish, or on both mechanisms working together. Finish to finish and finish to substrate incompatibility are due to mismatched mechanical properties, or poor surface preparation. When either or both of these conditions exist, the bond between surface and finish, or finish and older finish, is not great enough for adhesion and the finish will soon peel or flake off. In the interface, shear tension is created and the materials pull apart. Many of the more elastic modern finishes used on tombs in the past were not compatible with the brittle lime washes originally on the surface. These modern organic finishes are also less environmentally stable and have yellowed and failed due to sunlight and UV degradation.

Fig. 6.21 Thick layers of peeling modern surface finishes, Incomplete coverage and excessive biological growth in all the cracks and openings. Studio photograph, March 2001.

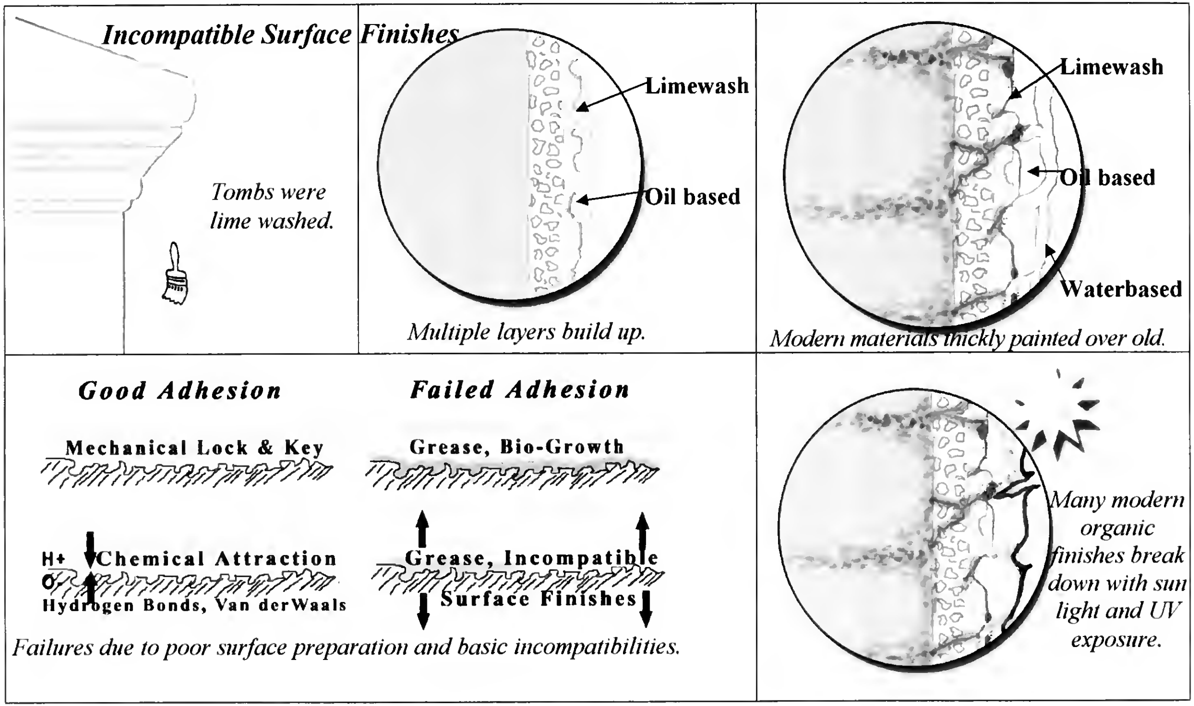


Fig. 6.22 Scenario: Incompatible surface finishes.

6.3.6 Incompatible Patches & Repairs

In some tombs, rather than stabilize and restore, the worst areas of lost stucco were patched with modern cement. The moisture movement and strength properties of the patch are greatly different from the surrounding material. The older stucco is generally more absorptive and can wet out more, but has a much faster drying rate. At the interface, the cement patch inhibits the evaporative process of drying, keeping the seam area wetter and the materials beneath the patch damp. Expansive salts from the damage products of cement develop at the seam. Also at this point stresses due to expansion, hygric movement and dissolution transfer to the weaker material, causing the most damage to the historic material. Removal of bad repairs often causes even greater mechanical damage. The high adhesive strength of the repair would bond tightly to the wet brick or stucco substrate with compromised cohesive strength, thus resulting is further destruction of the historic material as the repair is removed. This creates a situation in which the cement repairs cannot be considered reversible, repairable or sacrificial because they cannot be removed from the brick without causing greater damage. The incompatible repair ultimately requires total replacement.

Fig. 6.23 Cement patch pushed off of original due to damaged material and salts.

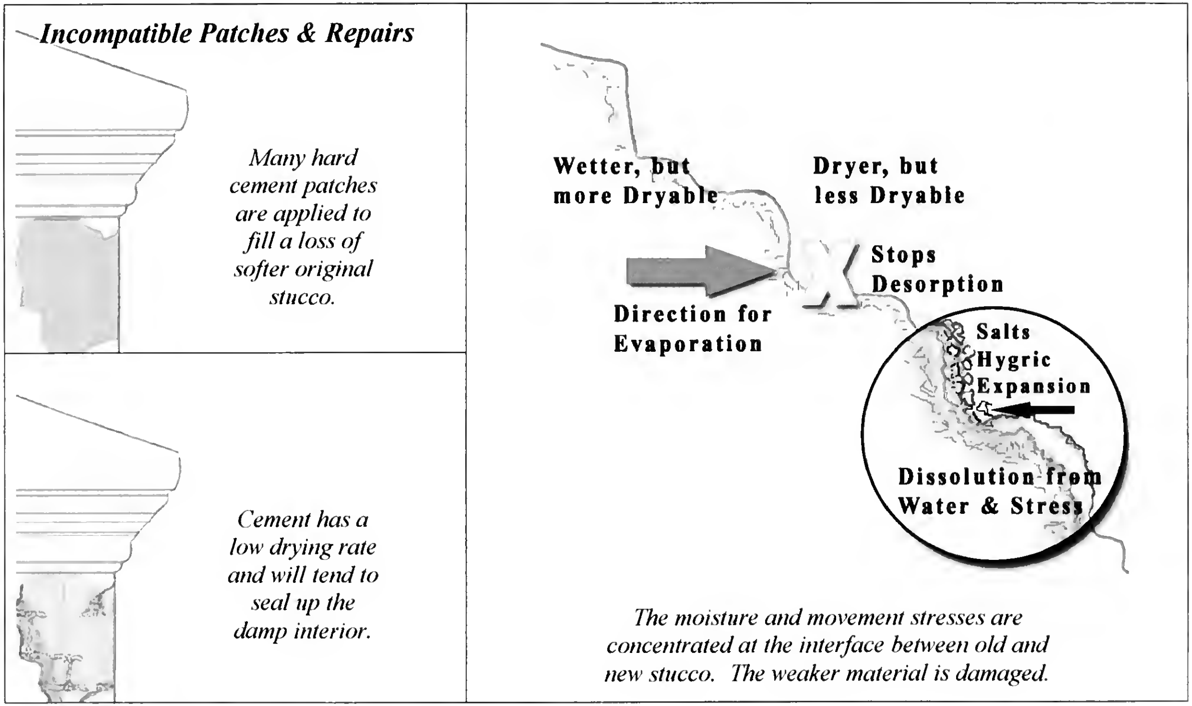


Fig. 6.24 Scenario: Incompatible patches & repairs.

6.3.7 The Cement Straight-Jacket

One solution to failing tombs has been to completely encase them in cement. Water will still enter the structure through rising damp and any small micro-cracks that develop, the internal porous materials will still respond to moisture movement and will try to move, creating stress within the system. The strength of the concrete shell will hold these stresses in check for some time until they become too great, when the pressure will be relieved through the development of a structural rupture. These cracks can be catastrophic to the structure and very hard to repair without dismantling the wall and resetting the brick. A related solution of the new cement roof has also damaged many tombs by adding much greater weight loads to the structures than the tombs were ever designed to carry.

Fig. 6 25 The sides of a cement encased tomb beginning to break up.

Fig. 6.26 The cement encasing the oldest section of wall vaults is cracking and has been poorly patched.

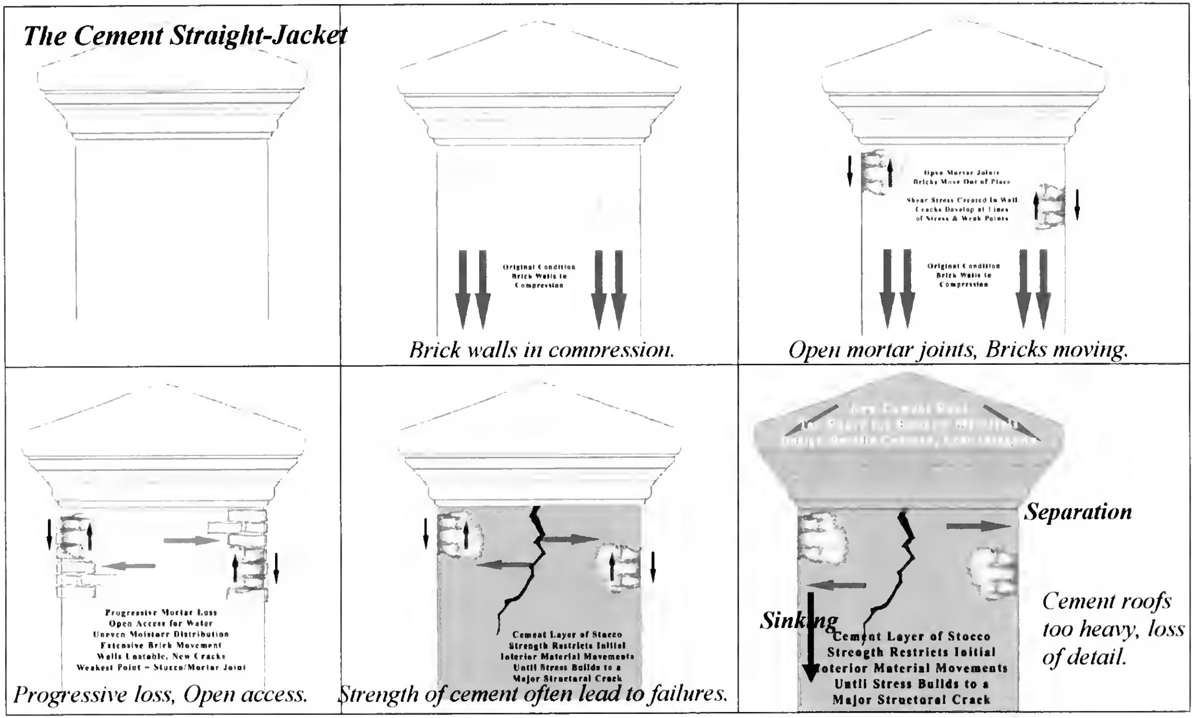


Fig. 6.27 Scenario: The cement straight-jacket.

7.0 Recommendations

7.1 Recommendations for Further Research

During this research, there were many issues that could not be studied in the limited time period. More environmental information is required to fully understand the changes that occur within any tomb given the weather patterns, materials of construction, and micro climate including the surrounding precinct material and other paved areas and soil rheology. In a future research project, it would also be instructive to install environmental probes in the ground, on the exterior of a tomb, within the tomb and within the different structural system components to monitor temperature and humidity changes over time. That information might lead to better conclusions on the subsidence of tombs historically and under current conditions.

The construction materials not covered in this research, particularly marble and metalwork, are very worthy of more research. In addition, a full study of surface finish remains would provide a better understanding of the palette of colors seen within the site throughout its history. There remain technical questions on the type and thickness of finishes and their resultant impact on stucco performance.

The database that was created for the Survey contains the "First Visible Date" for many of the tombs, and it is tempting to use those dates for research into conditions, style and construction materials. Unfortunately, too many of the dates that are visible are not believed to be the earliest date, and the date information was not heavily used herein. Local archival work with the Archdiocese interment records and the WPA survey made in the 1930s, further informed by local historians and genealogists, could improve the veracity of the data references.

Another area for archival research is a continuation of the study that Henry Krotzer and others have made of the diaries and account books of builders and merchants providing the services and materials for construction in the 1800s. Those accounts may also contain more information on specific tombs and families to aid in the ongoing tomb restoration work sparked by the Alley 9-L tombscape restoration project funded by a grant from *Save America's Treasures*.

This research touched on the possibility of stucco porosity analysis by microscopy and image analysis. With the universe of samples now available from St. Louis Cemetery No. 1, further research should be considered to compare and contrast available methods and techniques. With the advances in digitization that have been made in the most recent release of ESRI ArcView® 8.0, mapping thin-sections for porosity, mineral content and other matrix

morphology questions might be more easily managed in GIS than in the currently promoted imaging programs developed for the biological sciences, such as Bioquant.®

The development of robust models for decay of historic resources has been on the top of the lists for needed research at many of the conferences on conservation and deterioration of stone, brick and mortar. More research is needed to develop workable models that are practical and understandable enough that they will be used. Van Balen, et. al. have worked to develop a Masonry Damage Diagnostic System MDDS decision tree with a detailed questionnaire and selected test methods to determine the type of damage and make determinations of the damaging process between. They define 11 different processes: frost damaging process, salt crystallization process, environmental pollution chemical process, surface erosion process, water penetration process, mechanical damaging process, surface deposition without chemical process, condensation process, structural damaging process, iron corrosion process and biological process. The model's complexity and the documentation required, however, may keep the use of the model low.[148]

Viles, reporting for the group session on mechanisms, modeling and prediction said: "Our aim in this section is to indicate ways in which we can improve the utility of our scientific knowledge of damage mechanisms and rates ... by a) overcoming the scale

[148] K. Van Balen, K. "Monitoring of Degradation: Selection of Treatment Strategies." In Saving Our Architectural Heritage: The Conservation of Historic Stone Structures, Report of the Dahlem Workshop, Berlin, March 3-8, 1996, N.S. Baer and R. Snethlage, eds. (New York: John Wiley & Sons Ltd., 1997), 167-179.

differences between the microscopic damage processes and their manifestation at the visible scale on buildings and b) using the copious amounts of data produced to develop predictive models. An overall goal is the use of modeling techniques for simplifying the range and resolution of data that need to be colleted for any one project. ... The goal of modeling damage is to enable prediction. ... modeling has the potential to link the microscale with the mesoscale."[149]

7.2 Recommendations for Aboveground Cemetery Guidelines

This research has contributed to the base of knowledge on the brick, mortar and stucco used to build the tombs of St. Louis Cemetery No. 1. The decay sketches and scenario schematics bring a considerable amount of technical theory and research into short form visuals for the education of a larger group of owners, managers and other interested supporters of the restoration programs at the site. Many of these images will be provided to the Louisiana Division of Historic Preservation, Office of Cultural Development and Tourism along with the Phase 2 Project *Guidelines for the Preservation of Above-Ground Cemeteries* and it is recommended that they be widely distributed.

[149] H.A. Viles, et al. "Group Report: What is the State of Our Knowledge of the mechanisms of Deterioration and How Good are our Estimates of Rates of Deterioration?" *Saving Our Architectural Heritage: The Conservation of Historic Stone Structures, Report of the Dahlem Workshop*, Berlin, March 3-8, 1996, N.S. Baer and R. Snethlage, eds. (New York: John Wiley & Sons Ltd., 1997), 108-109.

8.0 Conclusions

The true root cause for the deterioration results seen at St. Louis Cemetery No. 1 is a lack of cyclical maintenance and timely periodic repair. The weathering and ageing of porous building materials is to be expected. The surface finishes and stucco layers were applied as sacrificial finishes to protect the interior structural elements. Webster's unabridged dictionary defines sacrificial as "relating to sacrifice, the destruction or surrender of something for the sake of something else; giving up of some desirable thing in behalf of a higher object." In building materials, sacrificial implies impermanence, and the original intent was that the sacrificial finishes, both stucco and lime washes, would be replaced more frequently that the structural body when their effectiveness became reduced.

Periodic sealing of small cracks in stucco from the White, Tan and Dark Tan groups would have kept these finishes effective for many decades, possibly longer. Since the stucco was not repaired, or was repaired or encased with incompatible materials, the different responses to moisture have made each material respond and move differently. Movement has occurred to relieve mechanical stresses built up through material expansion and deformation or through chemical processes, both driven primarily by the movement, or lack of movement, of moisture through the composite system. In all cases, this has led to escalating damage, whether visible or remaining hidden for years.

Water cannot be removed from the environment at St. Louis Cemetery No. 1. Once tombs are stabilized and structural issues are repaired, plans are to grout, repoint and stucco restored tombs with mixes based on compatible materials with good performance characteristics for the environment, such as hydraulic lime. This research indicates that many of the original stucco layers contain hydraulic components for greater protection in such a damp environment, and that the weak mortar joints did not, but perhaps should have. The current use of hydraulic lime as the restoration mortar and stucco should ensure better stability to the dissolving actions of water on the mortar and should be comparable to stucco used in the past in terms of its compatibility with the soft interior brick.

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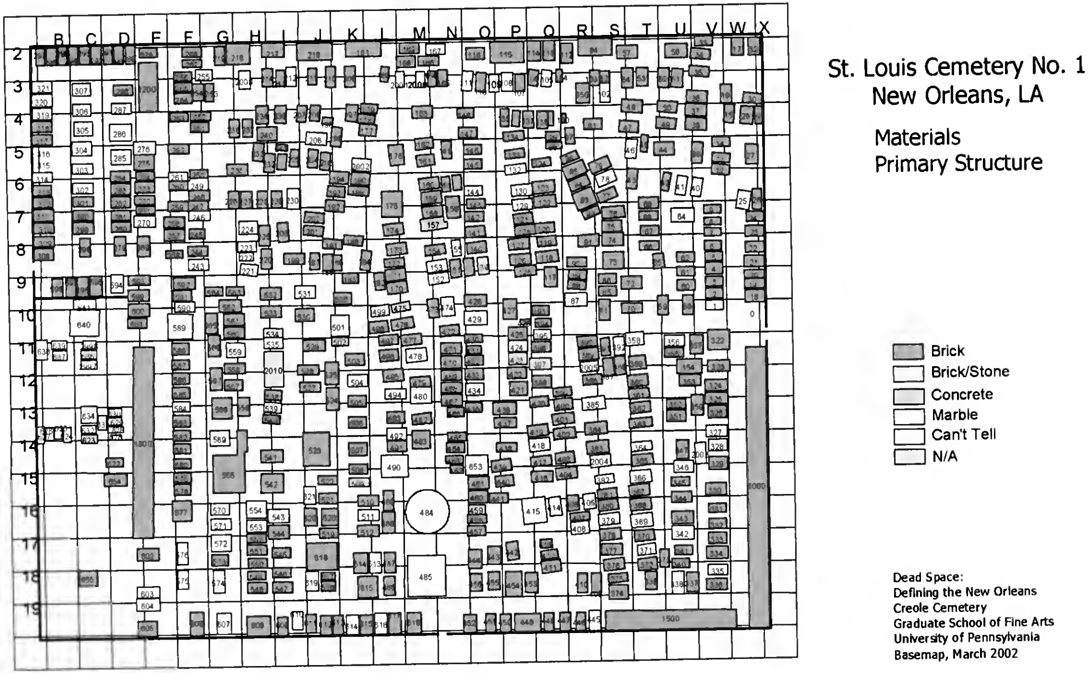
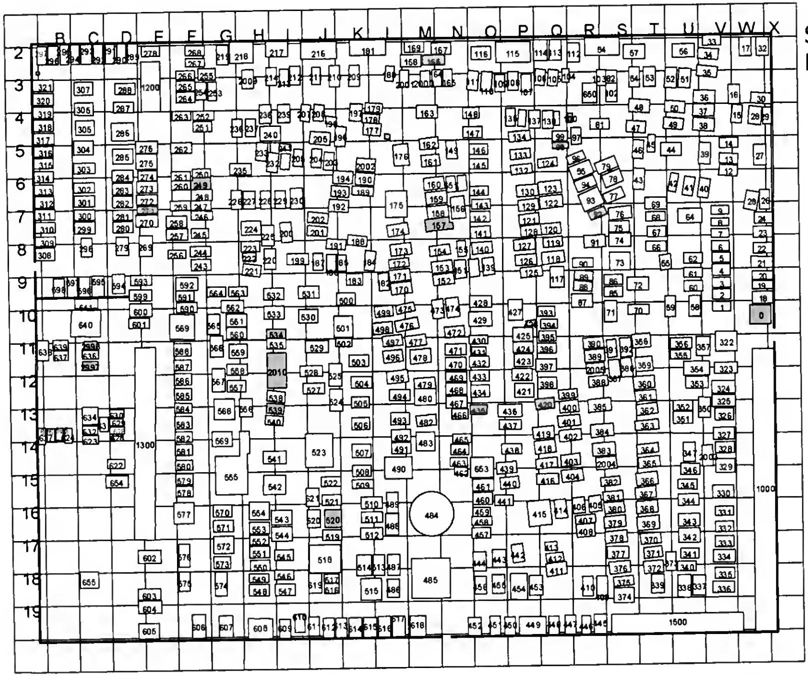
APPENDICES

Appendix A

GIS Maps of Conditions


St. Louis Cemetery No. 1
New Orleans, LA
Materials
Primary Structure
Brick
Brick/Stone
Concrete
Marble
Can't Tell
N/A
Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002

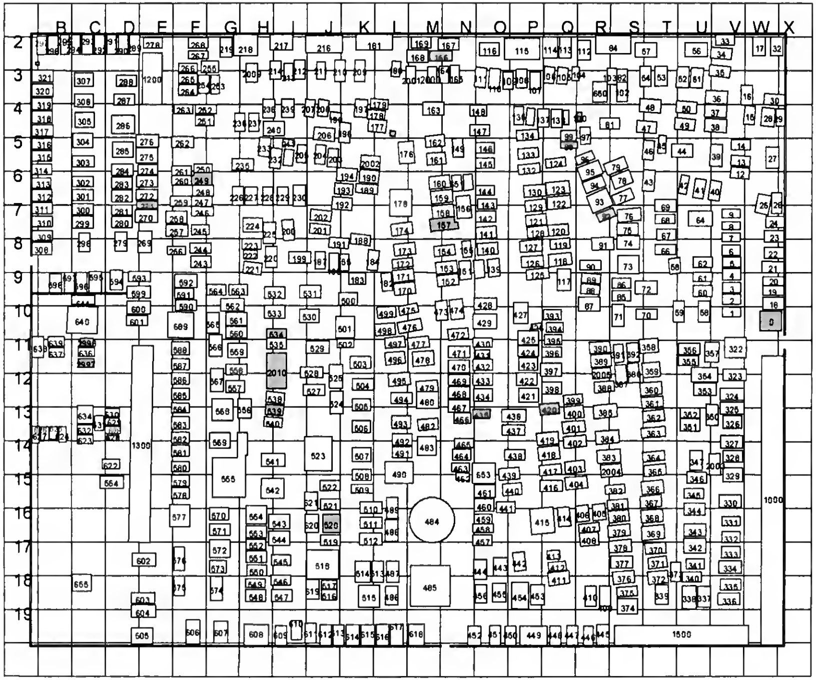


St. Louis Cemetery No. 1
New Orleans, LA

Condition
Primary Structure

Very Poor
Poor
Moderate
Good

Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002

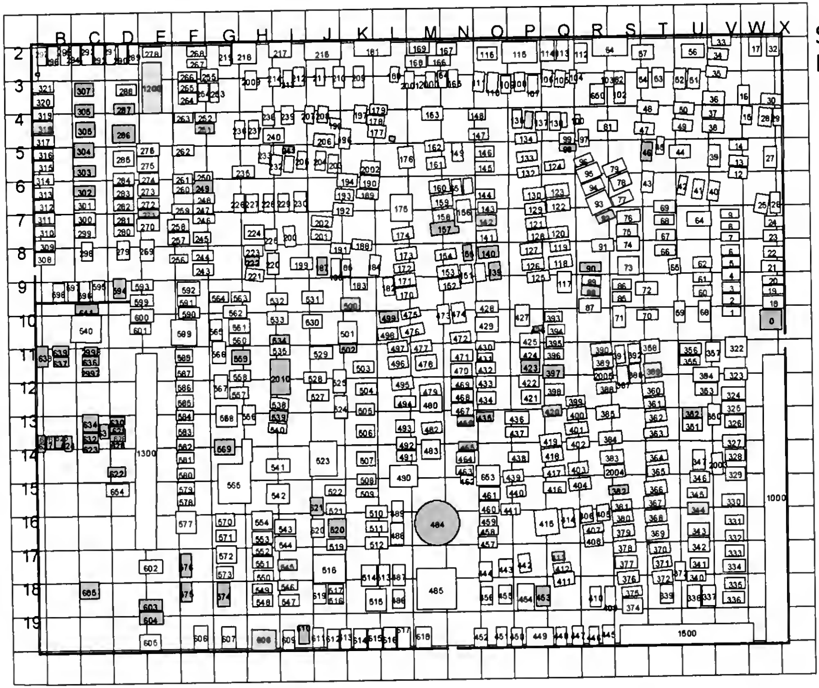


St. Louis Cemetery No. 1
New Orleans, LA

Condition
Roof

Very Poor
Poor
Moderate
Good

Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002

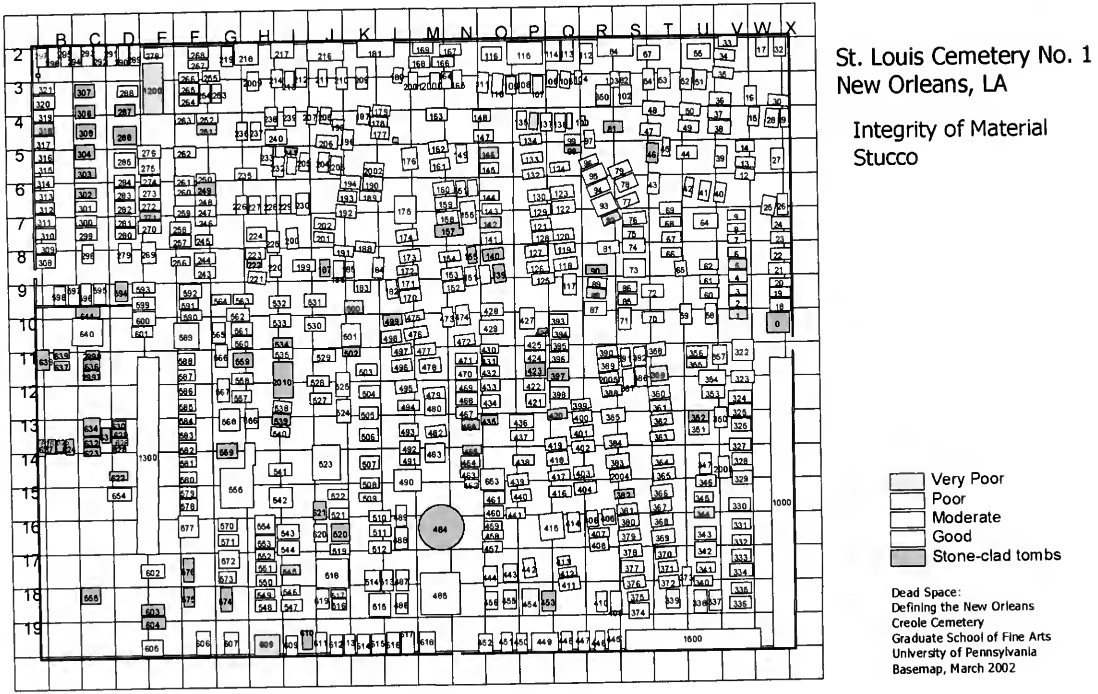


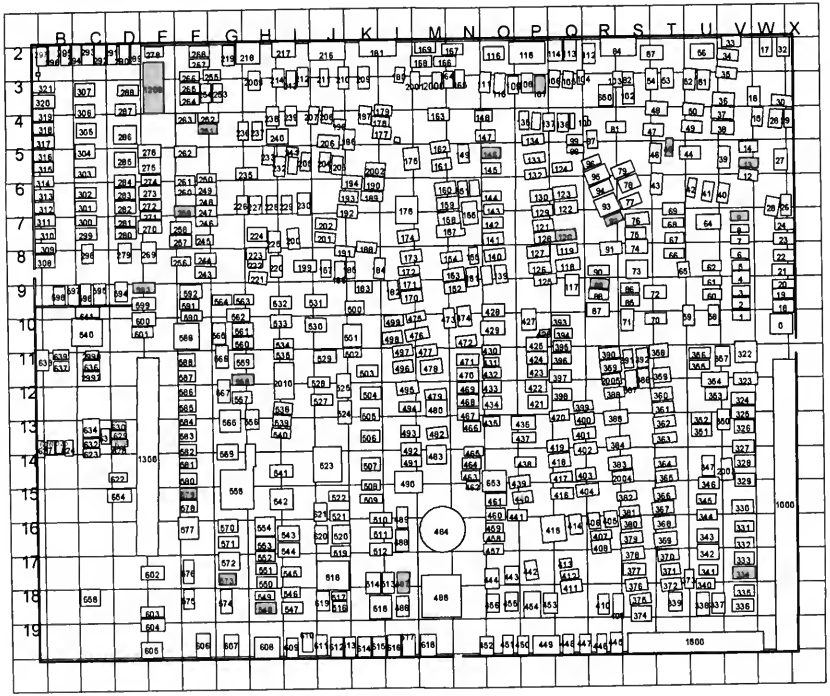
St. Louis Cemetery No. 1
New Orleans, LA

Condition
Stucco

- Very Poor
- Poor
- Moderate
- Good
- N/A

Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002

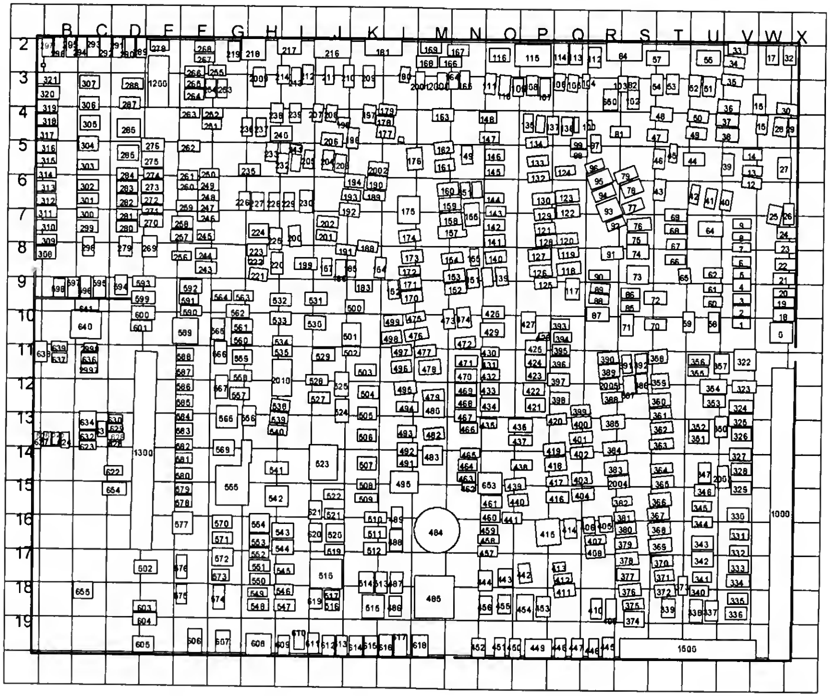

St. Louis Cemetery No. 1
New Orleans, LA
Integrity of Material
Stucco
Very Poor
Poor
Moderate
Good
Stone-clad tombs
Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002



St. Louis Cemetery No. 1
New Orleans, LA

Tombs Sampled
for Brick

Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002



St. Louis Cemetery No. 1
New Orleans, LA

Tombs Sampled
for Stucco

Dead Space:
Defining the New Orleans
Creole Cemetery
Graduate School of Fine Arts
University of Pennsylvania
Basemap, March 2002

Appendix B

Sampling Record

#	2	1st Date	1921
Dalberni/Clavin/Pecora			

Simple Parapet		Tan/Gray	
Sample	0002-01	17-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☑	☐	

Cornice altered – stucco'ed over

Tan-Gr, Cement layer, Samples have distinct layers,

#	2	1st Date	1921
Dalberni/Clavin/Pecora			

Simple Parapet		Tan/Gray	
Sample	0002-02	17-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cornice altered – stucco'ed over

Tan layer under cement, finish peels off.

#	2	1st Date	1921
Dalberni/Clavin/Pecora			

Simple Parapet		Tan/Gray	
Sample	0002-03	17-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☐	☑	

Cornice altered – stucco'ed over

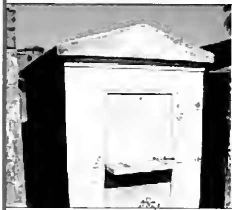
#	2	1st Date	1921
Dalberni/Clavin/Pecora			

Simple Parapet		Tan/Gray	
Sample	0002-05	29-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☑	☐	

Cornice altered – stucco'ed over

WhiteGray stucco,

#	4	1st Date	1958
Marant/Gallard/LaFluer			



Simple Platform		Tan	
Sample	0004-01	21-Mar-02	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☑	☐	

No Comment

#	9	1st Date	1822
deLaronde			

Simple Platform		Tan/Gray	
Sample	0009-03	17-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs	MVT	Grav	
☑	☐	☑	

Material integrity questionable, but more than 75% of material is original, should restore this one. Earlier layer was limewashed, Big cracks, not telescoping, stucco brittle, not flexible.

#	9	1st Date	1822
deLaronde			

Simple Platform		Tan/Gray	
Sample	0009-04	17-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
✓		✓	☐

Material integrity questionable, but more than 75% of material is original, should restore this one. Earlier layer was limewashed, Big cracks, not telescoping, stucco brittle, not flexible.

#	9	1st Date	1822
deLaronde			

Simple Platform		Tan/Gray	
Sample	0009-05	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
✓		☐	✓

Material integrity questionable, but more than 75% of material is original, should restore this one. Earlier layer was limewashed, Big cracks, not telescoping, stucco brittle, not flexible.

#	9	1st Date	1822
deLaronde			

Simple Platform		Tan/Gray	
Sample	0009-07	27-Dec-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
✓		✓	✓

Material integrity questionable, but more than 75% of material is original, should restore this one. Earlier layer was limewashed, Big cracks, not telescoping, stucco brittle, not flexible.

Gray Outer layer

#	9	1st Date	1822
deLaronde			

Simple Platform		Tan/Gray	
Sample	0009-08	27-Dec-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
✓		☐	✓

Material integrity questionable, but more than 75% of material is original, should restore this one. Earlier layer was limewashed, Big cracks, not telescoping, stucco brittle, not flexible.

Tan Inner layer of stucco

#	9	1st Date	1822
deLaronde			

Simple Platform		Tan/Gray	
Sample	0009-09	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
☐		☐	☐

Material integrity questionable, but more than 75% of material is original, should restore this one. Earlier layer was limewashed, Big cracks, not telescoping, stucco brittle, not flexible.

Large samples, both layers

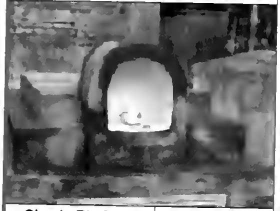
#	13	1st Date	1830
Esteve/Latil/Colongne			

Simple Platform		Tan	
Sample	0013-01	17-Nov-01	
Type	Brick with Stucco, Mortar		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs		MIT	Grav
✓		✓	✓

Recently restored by Upenn

Brick from pre-restoration, Hard SF.

#	13	1st Date	1830
Esteve/Latil/Colongne			



Simple Platform		Tan	
Sample	0013-02	27-Dec-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MIT	Grav	
✓	☐	☐	

Recently restored by Upenn

Tan, Take sample off of brick

#	13	1st Date	1830
Esteve/Latil/Colongne			

Simple Platform		Tan	
Sample	0013-03	27-Dec-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MIT	Grav	
✓	☐	✓	

Recently restored by Upenn

Small samples

#	14	1st Date	1849
Gaton/Place			

Simple Parapet		Tan/Gray	
Sample	0014-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MIT	Grav	
✓	☐	✓	

No Comment

Tan-Gr

#	14	1st Date	1849
Gaton/Place			

Simple Parapet		Tan/Gray	
Sample	14-02	18-Nov-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MIT	Grav	
✓	☐	✓	

No Comment

Tan layer beneath Gray

#	39	1st Date	9999
Mermillon/Oehmichen			

Simple Parapet		Tan/Gray	
Sample	0039-01	17-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	1	1	1
Moisture Abs	MIT	Grav	
✓	☐	✓	

No Stucco on roof. We should restore this one. Telescoping v. evident on right side. Originally built as 2 vaults with Parapet like the add-ons were becoming. Transitional.

Gray layer

#	39	1st Date	9999
Mermillon/Oehmichen			

Simple Parapet		Tan/Gray	
Sample	0039-03	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	1	1	1
Moisture Abs	MIT	Grav	
✓	✓	✓	

No Stucco on roof. We should restore this one. Telescoping v evident on right side. Originally built as 2 vaults with Parapet like the add-ons were becoming. Transitional.

Tan Stucco

#	39	1st Date	9999
Mermillon/Oehmichen			

Simple Parapet		Tan/Gray	
Sample	0039-04	21-Mar-02	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	1	1	1
Moisture Abs	MVT	Grav	
☐	☑	☐	

No Stucco on roof. We should restore this one. Telescoping v. evident on right side. Originally built as 2 vaults with Parapet like the add-ons were becoming. Transitional.

Cement stucco, SF under the cement layer

#	44	1st Date	1851
Sinnott			

Simple Platform		Gray	
Sample	0044-01	17-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
☑	☑	☑	

Unusual/non traditional cornice on roofline: possible alteration

Gray,

#	45	1st Date	1834
Martel			

Simple Parapet		Tan	
Sample	0045-01	17-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs	MVT	Grav	
☑	☑	☑	

No stucco on roof, 2-coat stucco work, but original, very coarse, Some telescoping, map cracking at parapet

Tan,

#	45	1st Date	1834
Martel			

Simple Parapet		Tan	
Sample	0045-02	18-Nov-01	
Type	Brick with Stucco, Mortar		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs	MVT	Grav	
☑	☑	☐	

No stucco on roof, 2-coat stucco work, but original, very coarse, Some telescoping, map cracking at parapet

#	45	1st Date	1834
Martel			

Simple Parapet		Tan	
Sample	0045-03	17-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs	MVT	Grav	
☑	☐	☑	

No stucco on roof, 2-coat stucco work, but original, very coarse, Some telescoping, map cracking at parapet

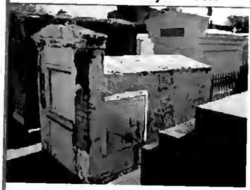
Large sample, more on brick if needed

#	53	1st Date	9999
Blank			

Simple Platform		Tan	
Sample	0053-02	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	1
Moisture Abs	MVT	Grav	
☑	☐	☐	

No stucco on roof

#	67	1st Date	1849
Prados/Tardy/Joubert			



Simple Parapet		Tan	
Sample	0067-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

New stucco on roof. May have begun as a step tomb, with added story and parapet

Tan, Small pieces only

#	89	1st Date	1922
Guibert			

Simple Platform		Tan	
Sample	0089-02	17-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs	MVT	Grav	
☑	☑	☑	

Red evident, blue color visible/parapet almost completely gone. Was limewashed right on old brick, stucco added later. Mix of brick sizes.

Large pieces

#	89	1st Date	1922
Guibert			

Simple Platform		Tan	
Sample	0089-03	17-Nov-01	
Type	Brick with Mortar		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs	MVT	Grav	
☑	☑	☐	

Red evident, blue color visible/parapet almost completely gone. Was limewashed right on old brick, stucco added later. Mix of brick sizes.

Brick was limewashed without stucco at one time.

#	89	1st Date	1922
Guibert			

Simple Platform		Tan	
Sample	0089-04	17-Nov-01	
Type	Brick with Mortar		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs	MVT	Grav	
☑	☑	☐	

Red evident, blue color visible/parapet almost completely gone. Was limewashed right on old brick, stucco added later. Mix of brick sizes.

Dk Tan

#	89	1st Date	1922
Guibert			

Simple Platform		Tan	
Sample	0089-05	17-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs	MVT	Grav	
☑	☐	☑	

Red evident, blue color visible/parapet almost completely gone. Was limewashed right on old brick, stucco added later. Mix of brick sizes.

Take sample from Brick

#	92	1st Date	1919
Illegible			

Simple Step		Tan	
Sample	0092-02	18-Nov-01	
Type	Brick with Mortar		
Cond.	PriSt	Roof	Stucco
	0	0	0
Moisture Abs	MVT	Grav	
☑	☑	☐	

Catastrophic structural failure: no form to adhere to. Date must be much earlier, 2x4x8.5 hand molded river brick.

Not local?? Very hard

#	92	*1st Date*	1919
Illegible			

Simple Step		Tan	
Sample	0092-03	27-Dec-01	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	0	0	0
Moisture Abs	*MVT*	*Grav*	
✓		✓	

Catastrophic structural failure: no form to adhere to. Date must be much earlier, 2x4x8.5 hand molded river brick.

Taken from Brick

#	107	*1st Date*	1867
Hagan			

Simple Parapet		Tan	
Sample	0107-01	18-Nov-01	
Type	Brick with Stucco, Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MVT*	*Grav*	
✓	✓	✓	

All original 2-coat stucco work, overall map cracking and some rising damp from neighboring precinct. Has slate roof cover.

Brick pieces (3)

#	107	*1st Date*	1867
Hagan			

Simple Parapet		Tan	
Sample	0107-02	18-Nov-01	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MVT*	*Grav*	
✓		✓	

All original 2-coat stucco work, overall map cracking and some rising damp from neighboring precinct. Has slate roof cover.

#	107	*1st Date*	1867
Hagan			

Simple Parapet		Tan	
Sample	0107-03	18-Nov-01	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MVT*	*Grav*	
✓			

All original 2-coat stucco work, overall map cracking and some rising damp from neighboring precinct. Has slate roof cover.

Dk Tan, Take sample from Brick

#	120	*1st Date*	1812
DeLarue/Boyere, et al			

Simple Parapet		Tan/Gray	
Sample	0120-01	18-Nov-01	
Type	Brick		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MVT*	*Grav*	
✓	✓		

Adhesion still good, even though there is some lost mortar where roof has been lost. Stucco still on brick, even where mortar washed out.

Thin layer of cement over a painted surface

#	120	*1st Date*	1812
DeLarue/Boyere, et al			

Simple Parapet		Tan/Gray	
Sample	0120-02a	28-Dec-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MVT*	*Grav*	
✓			

Adhesion still good, even though there is some lost mortar where roof has been lost. Stucco still on brick, even where mortar washed out.

#	120	*1st Date*	1812
DeLarue/Boyere, et al			

Simple Parapet		Tan/Gray	
Sample	0120-02b	28-Dec-01	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MIT*	*Grav*	
☑	☑	☐	

Adhesion still good, even though there is some lost mortar where roof has been lost. Stucco still on brick, even where mortar washed out.

SF removed

#	120	*1st Date*	1812
DeLarue/Boyere, et al			

Simple Parapet		Tan/Gray	
Sample	0120-03	18-Nov-01	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

Adhesion still good, even though there is some lost mortar where roof has been lost. Stucco still on brick, even where mortar washed out.

#	143	*1st Date*	1814
Fleitas/Guenard/Pineguy, et al			

Pediment Tomb		Tan	
Sample	0143-01	18-Nov-01	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	2	2
Moisture Abs	*MIT*	*Grav*	
☑	☐	☐	

Some loss of formal integrity due to loss of bricks. Rising Damp study written on this tomb, 5/2001. See report.

Dk Tan, Small pieces only

#	146	*1st Date*	1835
Dreux			

Simple Platform		Tan/Gray	
Sample	0146-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	0	1
Moisture Abs	*MIT*	*Grav*	
☑	☑	☐	

May be an earlier date on the bottom. Remaining stucco well bonded, good weathering, cracking at the top.

#	146	*1st Date*	1835
Dreux			

Simple Platform		Tan/Gray	
Sample	0146-02	18-Nov-01	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	0	1
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

May be an earlier date on the bottom. Remaining stucco well bonded, good weathering, cracking at the top.

#	146	*1st Date*	1835
Dreux			

Simple Platform		Tan/Gray	
Sample	0146-03	18-Nov-01	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	0	1
Moisture Abs	*MIT*	*Grav*	
☑	☑	☐	

May be an earlier date on the bottom. Remaining stucco well bonded, good weathering, cracking at the top.

Tan-Gr,

#	146	*1st Date*	1835
Dreux			

Simple Platform		Tan/Gray	
Sample	0146-05	29-Mar-02	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	0	1
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

May be an earlier date on the bottom. Remaining stucco well bonded, good weathering, cracking at the top.

Gray layer separated for testing

#	146	*1st Date*	1835
Dreux			

Simple Platform		Tan/Gray	
Sample	0146-06	29-Mar-02	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	0	1
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

May be an earlier date on the bottom. Remaining stucco well bonded, good weathering, cracking at the top.

Tan layer separated for testing

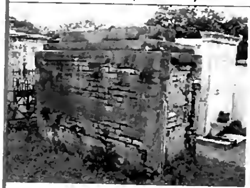
#	200	*1st Date*	1822
Sauve(Trudeau)			

Simple Platform		Tan/Gray	
Sample	0200-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	2
Moisture Abs	*MVT*	*Grav*	
☑	☑	☑	

2.5" handmade bricks on bottom, 2.5 smooth manmade bricks on top. Stucco with brickdust in the lower level, Bricks are the same size top and bottom, but looks added onto.

Gray layer, Cement layer of whitewashed original

#	200	*1st Date*	1822
Sauve(Trudeau)			

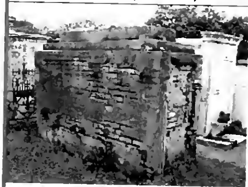


Simple Platform		Tan/Gray	
Sample	0200-03	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	2
Moisture Abs	*MVT*	*Grav*	
☑	☑	☑	

2.5" handmade bricks on bottom, 2.5 smooth manmade bricks on top. Stucco with brickdust in the lower level, Bricks are the same size top and bottom, but looks added onto.

Stucco with brick dust, Not quite large enough for MVT.

#	200	*1st Date*	1822
Sauve(Trudeau)			

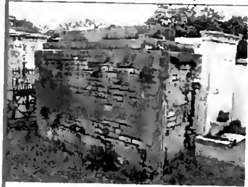


Simple Platform		Tan/Gray	
Sample	0200-04	21-Mar-02	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	2
Moisture Abs	*MVT*	*Grav*	
☑	☑	☐	

2.5" handmade bricks on bottom, 2.5 smooth manmade bricks on top. Stucco with brickdust in the lower level, Bricks are the same size top and bottom, but looks added onto.

DkTan, Cement Thin Coating

#	200	*1st Date*	1822
Sauve(Trudeau)			

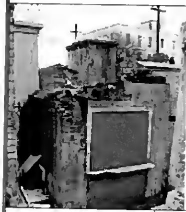


Simple Platform		Tan/Gray	
Sample	0200-05	21-Mar-02	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	2
Moisture Abs	*MVT*	*Grav*	
☑	☑	☑	

2.5" handmade bricks on bottom, 2.5 smooth manmade bricks on top. Stucco with brickdust in the lower level, Bricks are the same size top and bottom, but looks added onto.

Gray

#	203	1st Date	1831
Arnoult/Beaumont			



Simple Platform		Tan	
Sample	0203-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	2	1
Moisture Abs	MVT	Grav	
☑	☐	☐	

Red evident, Roof missing stucco

Tan, Small pieces only

#	207	1st Date	1853
Field			

Simple Platform		Tan	
Sample	0207-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Red evident, Roof top patched in places, Cornices not altered

Tan, Hard red coating,

#	208	1st Date	1868
Lamothe/Cavaroc			

Simple Platform		Tan/Gray	
Sample	0208-02	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	0	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cemented over orig.stucco, roof gone, marble slab used to close tomb, Resurfacing here didn't seem to cause the same problems as the heavier coats.

Gray layer of stucco,

#	208	1st Date	1868
Lamothe/Cavaroc			

Simple Platform		Tan/Gray	
Sample	0208-03	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	0	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cemented over orig.stucco, roof gone, marble slab used to close tomb, Resurfacing here didn't seem to cause the same problems as the heavier coats.

Tan stucco layer,

#	209	1st Date	9999
Societe des Enfants Bien Aimes			

Pediment Tomb		Tan	
Sample	0209-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs	MVT	Grav	
☑	☐	☐	

No Comment

Tan,

#	210	1st Date	1858
Bellouguet			

Pediment Tomb		Tan	
Sample	0210-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	1	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Roof stucco missing, Interlayer bowing

Tan,

#	226	1st Date	1806
Souterre			

Simple Parapet		Tan/Gray	
Sample	0226-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

No Comment

Tan-Gr, Took brick face,

#	226	1st Date	1806
Souterre			

Simple Parapet		Tan/Gray	
Sample	0226-02	11-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

No Comment

Gray layer only

#	226	1st Date	1806
Souterre			

Simple Parapet		Tan/Gray	
Sample	0226-03	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☐		☐	☐

No Comment

Tan

#	227	1st Date	9999
Blank			

Simple Parapet		Tan	
Sample	0227-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Large areas of patching on sides, roof, parapet removed.

Tan, Small pieces

#	228	1st Date	1803
Rigaud			

Simple Platform		Tan	
Sample	0228-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs		MVT	Grav
☑		☐	☐

Red evident

Tan, Hard red SF,

#	231	1st Date	1947
Collins/Sullivan/Wharton			

Simple Parapet		Tan	
Sample	0231-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MVT	Grav
☑		☐	☐

Lots of telescoping of bricks, Top tier and parapet added. Signified by mismatched sized tablets.

DkTan, Rubbery outer SF,

#	237	1st Date	9999
Blank			

Pediment Tomb		Tan	
Sample	0237-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Detachment & bowing of stucco layer

Hard red SF covers an earlier white

#	239	1st Date	1854
Pradat			

Simple Platform		Tan	
Sample	0239-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	3
Moisture Abs		MVT	Grav
☑		☐	☐

Top of roof partially restuccoed, cracking at rooftop needs attention

Tan,

#	239	1st Date	1854
Pradat			

Simple Platform		Tan	
Sample	0239-02	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	3
Moisture Abs		MVT	Grav
☑		☑	☐

Top of roof partially restuccoed, cracking at rooftop needs attention

Bowing out away from the bricks.

#	244	1st Date	9999
Durel			

Simple Parapet		Tan/Gray	
Sample	0244-01	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Roof restuccoed

Tan stucco only,

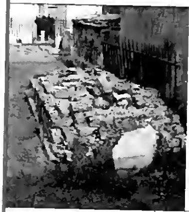
#	244	1st Date	9999
Durel			

Simple Parapet		Tan/Gray	
Sample	0244-02	12-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Roof restuccoed

Samples show cement layer over orig.

#	251	1st Date	1826
Labarre			



Simple Platform		Tan	
Sample	0251-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	1	0	0
Moisture Abs		MVT	Grav
☑		☑	☐

Nearly a ruin, River brick.

River brick

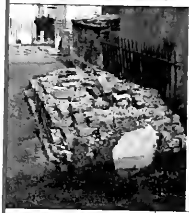
#	251	1st Date	1826
Labarre			

Simple Platform		Tan	
Sample	0251-03	18-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	1	0	0
Moisture Abs		MVT	Grav
✔		☐	✔

Nearly a ruin, River brick.

From Interior

#	251	1st Date	1826
Labarre			



Simple Platform		Tan	
Sample	0251-05	28-Dec-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	1	0	0
Moisture Abs		MVT	Grav
✔		☐	☐

Nearly a ruin, River brick.

Taken from brick

#	253	1st Date	1835
Establier/Ravain/Boulanger			

Simple Parapet		Gray	
Sample	0253-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MVT	Grav
✔		☐	☐

Roof Restuccoed

Gray, Small pieces only

#	254	1st Date	9999
Blank			

Simple Parapet		Tan	
Sample	0254-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs		MVT	Grav
✔		☐	☐

No Comment

Tan, Very hard coating of SF,

#	259	1st Date	1823
Caisergues			

Simple Platform		White	
Sample	0259-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs		MVT	Grav
✔		✔	☐

Very rough, Large aggregate stucco with crushed shells. High lime mortar with river brick. Testimony to early quality and compatibility of materials.

River brick, early white stucco with shells

#	259	1st Date	1823
Caisergues			

Simple Platform		White	
Sample	0259-02	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs		MVT	Grav
✔		✔	☐

Very rough, Large aggregate stucco with crushed shells. High lime mortar with river brick. Testimony to early quality and compatibility of materials.

River brick, Early stucco with shells

#	259	1st Date	1823
Caisergues			

Simple Platform		White	
Sample	0259-04	18-Nov-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs		MIT	Grav
✔		✔	✔

Very rough, Large aggregate stucco with crushed shells. High lime mortar with river brick. Testimony to early quality and compatibility of materials.

Very interesting early stucco with shells

#	259	1st Date	1823
Caisergues			

Simple Platform		White	
Sample	0259-05	18-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	2	0	1
Moisture Abs		MIT	Grav
✔		☐	✔

Very rough, Large aggregate stucco with crushed shells. High lime mortar with river brick. Testimony to early quality and compatibility of materials.

#	260	1st Date	1877
Baudier et al			

Simple Parapet		Tan	
Sample	0260-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
✔		☐	☐

Back and top of Parapet - Lost all stucco, the rest is good, caveau frontspiece missing

Tan,

#	263	1st Date	1853
Marrec/Groussol, et al			

Simple Platform		Tan	
Sample	0263-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MIT	Grav
✔		☐	☐

Blue color evident; probably used to be a parapet, but parapet is now missing.

Tan, Hard coating under white SF,

#	267	1st Date	1853
des Chapelles/Gerard			

Pediment Tomb		Tan	
Sample	0267-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
✔		☐	☐

No Comment

Tan. Very hard gray coating SF,

#	272	1st Date	9999
Blank			

Simple Parapet		Tan	
Sample	0272-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MIT	Grav
✔		☐	☐

Cement with small pebbles used for patching

Tan,

#	275	1st Date	1851
Olivier/Armingaud/Boudreau			

Wall Vault		Gray	
Sample	0275-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs	MVT	Grav	
✔	☐	☐	

Tomb layers, Additions,Only 1st level has finish now.

White cement, Stucco took brick face off.

#	275	1st Date	1851
Olivier/Armingaud/Boudreau			

Wall Vault		Gray	
Sample	0275-02	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs	MVT	Grav	
☐	✔	☐	

Tomb layers, Additions,Only 1st level has finish now.

MVT Size, White-Gray

#	291	1st Date	1927
Guma, et al			

Simple Parapet		Tan	
Sample	0291-01	13-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
✔	☐	☐	

No Comment

DkTan, Hard coating SF,

#	291	1st Date	1927
Guma, et al			

Simple Parapet		Tan	
Sample	0291-02	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☐	✔	☐	

No Comment

Front has hard shell finish, sample from side xfinish

#	298	1st Date	1852
Jourdain			

Pediment Tomb		Tan	
Sample	0298-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
✔	☐	☐	

No Comment

DkTan,

#	313	1st Date	1853
Riera, et al			

Pediment Tomb		Tan/Tan	
Sample	0313-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs	MVT	Grav	
✔	☐	☐	

Red color evident, Alteration evident, Re-roofed in cement

DkTan, Small chunk, lower finish

#	313	1st Date	1853
Riera, et al			

Pediment Tomb		Tan/Tan	
Sample	0313-02	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Red color evident, Alteration evident, Re-roofed in cement

Tan, Upper part of tomb, Very thick stucco,

#	330	1st Date	1853
Thomas/Hazeur			

Pediment Tomb		Tan	
Sample	0330-01	18-Nov-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs		MVT	Grav
☑		☐	☐

No Comment

DkTan,

#	334	1st Date	1838
Brousseau, et al			

Simple Parapet		Tan/Gray	
Sample	0334-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☑	☐

Roof wide open, missing bricks in parapet

Tan-Gr, Only orig. layer still on brick,

#	334	1st Date	1838
Brousseau, et al			

Simple Parapet		Tan/Gray	
Sample	0334-03	30-Dec-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Roof wide open, missing bricks in parapet

Separated tan layer only

#	334	1st Date	1838
Brousseau, et al			

Simple Parapet		Tan/Gray	
Sample	0334-04	08-Mar-02	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☑

Roof wide open, missing bricks in parapet

V. small pieces, mostly crushed

#	373	1st Date	1920
Robert, et al			

Simple Platform		Tan/Gray	
Sample	0373-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Orange evident

Tan-Gr,

#	373	1st Date	1920
Robert, et al			

Simple Platform		Tan/Gray	
Sample	0373-02	30-Dec-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MIT	Grav
☑		☐	☐

Orange evident

Gray on top of SF from earlier layer

#	373	1st Date	1920
Robert, et al			

Simple Platform		Tan/Gray	
Sample	0373-03	30-Dec-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MIT	Grav
☑		☐	☐

Orange evident

Original Tan layer only

#	381	1st Date	9999
Illegible			

Simple Platform		Tan	
Sample	0381-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
☑		☐	☐

No Comment

Tan,

#	383	1st Date	1924
Deangausse			

Pediment Tomb		Tan/Gray	
Sample	0383-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
☑		☐	☐

No Comment

Tan,

#	401	1st Date	9999
Blank			

Simple Platform		Tan	
Sample	0401-01	18-Nov-01	
Type	Other		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs		MIT	Grav
☑		☐	☐

No Comment

Roof tiles

#	401	1st Date	9999
Blank			

Simple Platform		Tan	
Sample	0401-02	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs		MIT	Grav
☐		☐	☐

No Comment

Tan, taken from brick

#	425	1st Date	1842
Backus/Morrison			

Simple Platform		Tan	
Sample	0425-01	08-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	2	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Roof open.

Tan

#	430	1st Date	1853
Prieur/Kernion			

Pediment Tomb		Tan	
Sample	0430-01	08-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MVT	Grav
☑		☐	☐

Possible addition of second story

Tan, From lower section of tomb

#	430	1st Date	1853
Prieur/Kernion			

Pediment Tomb		Tan	
Sample	0430-02	08-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MVT	Grav
☑		☐	☐

Possible addition of second story

DkTan, From upper part of tomb

#	439	1st Date	9999
Alaux			

Pediment Tomb		Tan	
Sample	0439-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MVT	Grav
☑		☐	☐

Lost roof ornament

Dk Tan

#	469	1st Date	1816
S. Armand/Degruy			

Pediment Tomb		Tan	
Sample	0469-01	08-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MVT	Grav
☑		☐	☐

Blue/grey color visible -- red beneath visible.

Dk Tan

#	487	1st Date	1838
Bertoniere, et al			

Simple Platform		Tan	
Sample	0487-01	08-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs		MVT	Grav
☑		☐	☐

Blue color evident

Dk tan

#	487	1st Date	1838
Bertoniere, et al			

Simple Platform		Tan	
Sample	0487-02	08-Mar-02	
Type	Brick		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs	MIT	Grav	
☑	☐	☐	

Blue color evident

Dk tan

#	487	1st Date	1838
Bertoniere, et al			

Simple Platform		Tan	
Sample	0487-03	08-Mar-02	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs	MIT	Grav	
☑	☐	☑	

Blue color evident

V. small pieces, mostly crushed

#	493	1st Date	1879
Locoul, et al			

Pediment Tomb		Tan	
Sample	0493-01	08-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MIT	Grav	
☑	☐	☐	

No Comment

Tan

#	503	1st Date	1848
Tricou/Pitot/Boudreaux			

Simple Parapet		Tan	
Sample	0503-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MIT	Grav	
☑	☐	☐	

No Comment

Tan,

#	505	1st Date	9999
Roché			

Simple Platform		Tan	
Sample	0505-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	1	0	1
Moisture Abs	MIT	Grav	
☑	☐	☐	

All stucco off of roof - Collapsed, Corner bricks missing on structure. Breached vault through roof. Blue/grey color visible on stucco.

Tsn,

#	508	1st Date	1853
Montreuil/Crocker			

Pediment Tomb		Tan	
Sample	0508-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	1
Moisture Abs	MIT	Grav	
☑	☑	☐	

No stucco left on roof, blue/grey

DkTan

#	518	*1st Date*	1887
Sodiedad Cervantes de B.M.			

Society		Tan	
Sample	0518-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	2	3
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

Badly cracking, Restored by Archdiocese.

DkTan,

#	522	*1st Date*	1851
Cassard, et al			

Simple Parapet		Tan/Tan	
Sample	0522-03	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	2	2
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

Marble front probably added, Stucco loss on roof, walls good.

Top layer,

#	522	*1st Date*	1851
Cassard, et al			

Simple Parapet		Tan/Tan	
Sample	0522-04	01-Jan-02	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	2	2
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

Marble front probably added, Stucco loss on roof, walls good.

DkTan, Hard layer coating under loose

#	525	*1st Date*	1851
Frey			

Simple Platform		Tan/Gray	
Sample	0525-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	2	1
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

Red Evident, No stucco on roof

DkTan-Gr,

#	540	*1st Date*	1920

Simple Platform		Tan	
Sample	0540-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	1	2
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

No Comment

Tan, thick pieces

#	541	*1st Date*	9999
Parker			

Pediment Tomb		Tan	
Sample	0541-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	1
Moisture Abs	*MVT*	*Grav*	
☑	☐	☐	

Large bowing areas,roof lost stucco

DkTan,

#	544	1st Date	9999
Bernard			

Pediment Tomb		Tan	
Sample	0544-02	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
✓	☐	☐	

Stucco missing at roofs edge and right inner wall, Bowing & delaminated.

White SF over a hard gray coating SF,

#	544	1st Date	9999
Bernard			

Pediment Tomb		Tan	
Sample	0544-03	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
✓	☐	☐	

Stucco missing at roofs edge and right inner wall, Bowing & delaminated.

Tan, SF removed

#	545	1st Date	9999
Blank			

Simple Platform		Tan	
Sample	0545-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	1	0
Moisture Abs	MVT	Grav	
✓	☐	☐	

No roof stucco

Tan, Hard beige SF,

#	548	1st Date	1820
Bofill/Grather			

Simple Parapet		Tan	
Sample	0548-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	3
Moisture Abs	MVT	Grav	
✓	✓	☐	

Red evident, addition evidence- early tablet and tablet typoology.

#	548	1st Date	1820
Bofill/Grather			

Simple Parapet		Tan	
Sample	0548-02	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	3
Moisture Abs	MVT	Grav	
✓	✓	✓	

Red evident, addition evidence- early tablet and tablet typoology.

Tan,

#	548	1st Date	1820
Bofill/Grather			

Simple Parapet		Tan	
Sample	0548-03	18-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	2	3
Moisture Abs	MVT	Grav	
✓	☐	✓	

Red evident, addition evidence- early tablet and tablet typoology.

#	548	1st Date	1820
Bofill/Grather			

Simple Parapet		Tan	
Sample	0548-04	21-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	3
Moisture Abs	MVT	Grav	
☐	☑	☐	

Red evident, addition evidence- early tablet and tablet typoology.

Tan, SF all worn off

#	549	1st Date	1923
Reine			

Simple Parapet		Tan	
Sample	0549-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
☑	☐	☐	

No Comment

Tan, Hard coating SF,

#	550	1st Date	1866
Barry			

Simple Platform		Tan	
Sample	0550-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
☑	☑	☐	

Red Evident, Several small open areas of stucco on left side, cornice muddied by sloppy repair

DkTan, Modern SF easily peels off,

#	551	1st Date	9999
Vaucresson			

Simple Parapet		Gray	
Sample	0551-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☑	☐	

Sloppy paint job

Gray,

#	552	1st Date	1804
Dussuau			

Simple Parapet		Tan/Gray	
Sample	0552-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Red evident, no stucco on roof

Gray, Many layers of color,

#	552	1st Date	1804
Dussuau			

Simple Parapet		Tan/Gray	
Sample	0552-02	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Red evident, no stucco on roof

Original Tan stucco layer, no SF

#	558	1st Date	9999
Illegible			

Simple Platform		Tan/Gray	
Sample	0558-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	1	1	2
Moisture Abs	MIT	Grav	
☑	☐	☐	

Reroofed, Girdle of cement, Where it broke, took brick, not flexible. Mix of handmade river and early machine made lake bricks.

3 layers of stucco, 1st two thick,

#	558	1st Date	9999
Illegible			

Simple Platform		Tan/Gray	
Sample	0558-02	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	1	1	2
Moisture Abs	MIT	Grav	
☑	☑	☐	

Reroofed, Girdle of cement, Where it broke, took brick, not flexible. Mix of handmade river and early machine made lake bricks.

Should try to find archival data

#	558	1st Date	9999
Illegible			

Simple Platform		Tan/Gray	
Sample	0558-03	18-Nov-01	
Type	Brick		
Cond.	PriSt	Roof	Stucco
	1	1	2
Moisture Abs	MIT	Grav	
☑	☑	☐	

Reroofed, Girdle of cement, Where it broke, took brick, not flexible. Mix of handmade river and early machine made lake bricks.

Poss. River brick, Alley 9L samples,

#	558	1st Date	9999
Illegible			

Simple Platform		Tan/Gray	
Sample	0558-04	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	1	1	2
Moisture Abs	MIT	Grav	
☑	☐	☑	

Reroofed, Girdle of cement, Where it broke, took brick, not flexible. Mix of handmade river and early machine made lake bricks.

Layer #2, Dk Tan

#	558	1st Date	9999
Illegible			

Simple Platform		Tan/Gray	
Sample	0558-05	01-Jan-02	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	1	1	2
Moisture Abs	MIT	Grav	
☑	☐	☑	

Reroofed, Girdle of cement, Where it broke, took brick, not flexible. Mix of handmade river and early machine made lake bricks.

Tan, 1st layer of stucco

#	558	1st Date	9999
Illegible			

Simple Platform		Tan/Gray	
Sample	0558-07	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	1	1	2
Moisture Abs	MIT	Grav	
☐	☐	☐	

Reroofed, Girdle of cement, Where it broke, took brick, not flexible. Mix of handmade river and early machine made lake bricks.

Gray, Top cement layer #3

#	562	1st Date	1929
Pillard, et al			

Simple Parapet		Tan/Tan	
Sample	0562-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Parapet probably added; cornice profile crude

1st layer of 2 layer tan/tan stucco

#	562	1st Date	1929
Pillard, et al			

Simple Parapet		Tan/Tan	
Sample	0562-02	01-Jan-02	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Parapet probably added; cornice profile crude

DkTan, Layers of SF

#	563	1st Date	1824
Baune, et al			

Simple Platform		Tan	
Sample	0563-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Red evident, Many cracksin roof stucco, left side mostly gone

Tan,

#	564	1st Date	9999
Lacombe			

Pediment Tomb		Tan	
Sample	0564-02	01-Jan-02	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

New roof, badly cracking though., alley 9L

Tan, Top white SF layer

#	565	1st Date	9999
Villavaso			

Pediment Tomb		Tan	
Sample	0565-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cement patching on roof, Possible addition of upper tier- cracking at seam, tablet system and scale of adjacent tombs.

DkTan,

#	573	1st Date	1853
Dubreuil			

Simple Parapet		Tan	
Sample	0573-01	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs	MVT	Grav	
☑	☑	☐	

Stucco missing on roof, Flexible stucco, adhesion good to brick, where bricks move, see telescoping.

#	573	1st Date	1853
Dubreuil			

Simple Parapet		Tan	
Sample	0573-02	18-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs	MVT	Grav	
☑	☐	☑	

Stucco missing on roof, Flexible stucco, adhesion good to brick, where bricks move, see telescoping.

#	573	1st Date	1853
Dubreuil			

Simple Parapet		Tan	
Sample	0573-03	18-Nov-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs	MVT	Grav	
☑	☑	☑	

Stucco missing on roof, Flexible stucco, adhesion good to brick, where bricks move, see telescoping.

DkTan, Big enough for MVT

#	577	1st Date	1819
Malard/Folger ,et al			

Pediment Tomb		Tan/Gray	
Sample	0577-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cement patching, stucco loss on roof, failing by splitting into three distinct bays. Wythes not laced together. Unusual cup-out of top layer of stucco in back. Sampled.

Tan, Orig. stucco, From front of tomb

#	577	1st Date	1819
Malard/Folger ,et al			

Pediment Tomb		Tan/Gray	
Sample	0577-02	14-Oct-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	2	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cement patching, stucco loss on roof, failing by splitting into three distinct bays. Wythes not laced together. Unusual cup-out of top layer of stucco in back. Sampled.

Gray, Cement coating from front of tomb

#	577	1st Date	1819
Malard/Folger ,et al			

Pediment Tomb		Tan/Gray	
Sample	0577-04	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	2	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cement patching, stucco loss on roof, failing by splitting into three distinct bays. Wythes not laced together. Unusual cup-out of top layer of stucco in back. Sampled.

DkTan, Outer layer, back of tomb,

#	579	1st Date	9999
St. Cyr			

Simple Parapet		Tan	
Sample	0579-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs	MVT	Grav	
☑	☐	☐	

Cement patching on the roof failed

Tan,

#	579	1st Date	9999
St. Cyr			

Simple Parapet		Tan	
Sample	0579-02	18-Nov-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
☑		☑	☐

Cement patching on the roof failed

#	579	1st Date	9999
St. Cyr			

Simple Parapet		Tan	
Sample	0579-03	18-Nov-01	
Type	Brick		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
☑		☑	☐

Cement patching on the roof failed

#	579	1st Date	9999
St. Cyr			

Simple Parapet		Tan	
Sample	0579-05	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	2	1	1
Moisture Abs		MIT	Grav
☑		☑	☐

Cement patching on the roof failed

Tan

#	581	1st Date	9999
Blank			

Simple Platform		Gray	
Sample	0581-01	18-Nov-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
☑		☑	☑

Atypical tomb; questionable formal integrity. Inflexible cement, big cracks.

Gray,

#	582	1st Date	1859
Roudanez			

Simple Platform		Tan/Gray	
Sample	0582-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs		MIT	Grav
☑		☐	☐

New roof, Edges on base exposed. odd roof form

Tan,

#	593	1st Date	9999
Blank			

Simple Platform		Tan	
Sample	0593-02	14-Oct-01	
Type	Brick with Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs		MIT	Grav
☑		☑	☐

Lots of missing stucco on roof, orange/red

#	593	1st Date	9999
Blank			

Simple Platform	Tan		
Sample	0593-03	01-Jan-02	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs	MVT	Grav	
☐	☐	☐	

Lots of missing stucco on roof, orange/red

Hard red coating SF

#	593	1st Date	9999
Blank			

Simple Platform	Tan		
Sample	0593-04	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs	MVT	Grav	
☑	☐	☐	

Lots of missing stucco on roof, orange/red

Tan

#	596	1st Date	1822
Delhom/Qurazzaro			

Simple Platform	Tan/Gray		
Sample	0596-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
☑	☐	☐	

Restuccoed with cement,cement roof any/all detail missing

Tan,

#	597	1st Date	1858
Loew			

Simple Platform	Tan/Gray		
Sample	0597-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	3
Moisture Abs	MVT	Grav	
☑	☐	☐	

Badly racking, Restuccoed w/ cement, new roof

Tan-Gr,

#	600	1st Date	1824
Colin, et al			

Pediment Tomb	Tan/Gray		
Sample	0600-02	18-Nov-01	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs	MVT	Grav	
☑	☑	☐	

Coated in cement, Roof totally exposed, most of left side exposed.

Tan-Gr,

#	600	1st Date	1824
Colin, et al			

Pediment Tomb	Tan/Gray		
Sample	0600-03	18-Nov-01	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs	MVT	Grav	
☑	☐	☑	

Coated in cement, Roof totally exposed, most of left side exposed.

#	600	1st Date	1824
Colin, et al			

Pediment Tomb		Tan/Gray	
Sample	0600-04	29-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs		MIT	Grav
☑		☑	☑

Coated in cement, Roof totally exposed, most of left side exposed.

Tan layer separated for testing

#	600	1st Date	1824
Colin, et al			

Pediment Tomb		Tan/Gray	
Sample	600-05	29-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	1	1
Moisture Abs		MIT	Grav
☐		☐	☑

Coated in cement, Roof totally exposed, most of left side exposed.

Gray layer separated for testing

#	601	1st Date	9999
Blank			

Simple Platform		Tan/Gray	
Sample	0601-02	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MIT	Grav
☑		☐	☐

Top and sides restuccoed in gray cement

Tan layer only

#	601	1st Date	9999
Blank			

Simple Platform		Tan/Gray	
Sample	0601-03	01-Jan-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	2	2
Moisture Abs		MIT	Grav
☑		☐	☐

Top and sides restuccoed in gray cement

Gray layer only

#	602	1st Date	9999
Blank			

Pediment Tomb		Tan	
Sample	0602-02	01-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
☑		☑	☑

Patched in cement, small areas, Very bad peeling finish

White, Separated to test.

#	612	1st Date	9999
Rousseau			

Simple Platform		Gray	
Sample	0612-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	3	2
Moisture Abs		MIT	Grav
☑		☐	☐

Bad delamination of stucco, SF not rubbery, unusual roof form; looks like a replacement.

Gray,

#	620	1st Date	1847
Rasch/Behn/Wibray/Layton			

Simple Platform		Tan	
Sample	0620-01	14-Oct-01	
Type	Stucco with Finish		
Cond.	PriSt	Roof	Stucco
	3	1	2
Moisture Abs	MIT	Grav	
✓	☐	☐	

No Comment

Tan,

#	1200	1st Date	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-01e	01-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	1	1	0
Moisture Abs	MIT	Grav	
✓	☐	✓	

Samples of river brick already at lab.
See Hannah-Hinchman 5/2001 report.

East Section, Gray Cement mostly

#	1200	1st Date	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-02m	01-Mar-02	
Type	Stucco		
Cond.	PriSt	Roof	Stucco
	1	1	0
Moisture Abs	MIT	Grav	
✓	☐	✓	

Samples of river brick already at lab.
See Hannah-Hinchman 5/2001 report.

Mid Section, White

#	1200	1st Date	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-03e	01-Mar-02	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	1	1	0
Moisture Abs	MIT	Grav	
✓	☐	☐	

Samples of river brick already at lab.
See Hannah-Hinchman 5/2001 report.

East section

#	1200	1st Date	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-04m	01-Mar-02	
Type	Mortar		
Cond.	PriSt	Roof	Stucco
	1	1	0
Moisture Abs	MIT	Grav	
✓	☐	☐	

Samples of river brick already at lab.
See Hannah-Hinchman 5/2001 report.

Mid section

#	1200	1st Date	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-05e	01-Mar-02	
Type	Brick		
Cond.	PriSt	Roof	Stucco
	1	1	0
Moisture Abs	MIT	Grav	
✓	✓	☐	

Samples of river brick already at lab.
See Hannah-Hinchman 5/2001 report.

East Vaults

#	1200	*1st Date*	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-06m	01-Mar-02	
Type	Brick		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	1	0
Moisture Abs	*MIT*	*Grav*	
☑	☑	☐	

Samples of river brick already at lab. See Hannah-Hinchman 5/2001 report.

Mid Vaults

#	1200	*1st Date*	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-07e	21-Mar-02	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	1	0
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

Samples of river brick already at lab. See Hannah-Hinchman 5/2001 report.

East Section, Probably not original

#	1200	*1st Date*	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-08	21-Mar-02	
Type	Stucco		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	1	0
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

Samples of river brick already at lab. See Hannah-Hinchman 5/2001 report.

Mid section,White Lime Stucco like 259.

#	1200	*1st Date*	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-09	21-Mar-02	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	1	0
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

Samples of river brick already at lab. See Hannah-Hinchman 5/2001 report.

East, Tan Mortar

#	1200	*1st Date*	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-11e	21-Mar-02	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	1	0
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

Samples of river brick already at lab. See Hannah-Hinchman 5/2001 report.

East, White mortar

#	1200	*1st Date*	1813
Treme Alley Right, 8 4-high Vaults			

Wall Vault		White	
Sample	1200-12m	21-Mar-02	
Type	Mortar		
Cond.	*PriSt*	*Roof*	*Stucco*
	1	1	0
Moisture Abs	*MIT*	*Grav*	
☑	☐	☑	

Samples of river brick already at lab. See Hannah-Hinchman 5/2001 report.

Mid vaults, White, Lots of shell bits

#	1300	*1st Date*	1818
Treme Alley Left, 24-26 3-high Vaults			

Wall Vault		Tan/Gray	
Sample	1300-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	1
Moisture Abs	*MVT*	*Grav*	
✔	☐	✔	

Some areas are bare, others restuccoed in cement, unpainted.

Cement on the wall vaults,

#	1300	*1st Date*	1818
Treme Alley Left, 24-26 3-high Vaults			

Wall Vault		Tan/Gray	
Sample	1300-02	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	1
Moisture Abs	*MVT*	*Grav*	
✔	☐	☐	

Some areas are bare, others restuccoed in cement, unpainted.

Original stucco layer,

#	2005	*1st Date*	9999
Jacobs-McNamara			

Pediment Tomb		Gray	
Sample	2005-01	18-Nov-01	
Type	Stucco with Finish		
Cond.	*PriSt*	*Roof*	*Stucco*
	3	3	3
Moisture Abs	*MVT*	*Grav*	
✔	☐	☐	

Perpetual Care

PC Tomb, small piece

Appendix C

Experimental Data

Table 9 - Total Immersion Tests on Stucco

Sorted by Tomb Number

Sample	Stucco Type	First Date	Mo Dry Weight	Msat %	Va ml Displ	% Porosity	Init. Slope	Thick	Comments-End	Color	Texture	Aggregate	Mohs Hardness	Texture Grit	Grind Diff	Ease to Break
0002-01	Tan-Gr	1921	13.3	7.52%	6	16.7%	0.0094	2.87	Sl. Discoloration	Gley1 8/N	Medium	Sub-rounded	4	320	3	3
0002-02	Tan	1921	13.00	13.08%	6	28.3%	0.0263			10YR 7/2	Coarse	Sub-angular	2.5	220	2	1
0002-05	Gray	1921	18.71	12.24%	9	25.4%	0.0250			White	Medium	Sub-angular	3	120	2	2
0004-01	DkTan	1958	6.7	7.46%	4	12.5%	0.0112	2.24	Sl. Discoloration	10YR 6/2	Coarse	Sub-rounded				
0009-07	Gray	1822	10.6	10.38%	4	27.5%	0.0189	2.17		7.5YR 8/1	Medium	Rounded				
0009-07	Gray	1822	11.86	6.24%	5	14.8%	0.0057			7.5YR 8/1	Medium	Rounded	4	120	3	3
0009-08	Tan	1822	16.9	10.65%	10	18.0%	0.0118	3.77	Sl. Discoloration	10YR 7/1	Coarse	Sub-angular	3	220	2	2
0009-08	Tan	1822	25.85	10.06%	14	18.6%	0.0089		Sl. Disaggregation	10YR 7/1	Coarse	Sub-angular				
0013-02	Tan-SF	1830	16.9	11.24%	8	23.8%	0.0104	4.90	Sl. Disaggregation	10YR 8/1	Medium	Sub-angular	3	220	1	2
0014-01	Tan-Gr	1849	4.7	8.51%	2	20.0%	0.0213	1.59		10YR 8/1	Medium	Sub-rounded				
0014-02	Gray	1849	9.11	8.78%	5	16.0%	0.0123			7.5YR 6/1	Medium	Sub-angular				
0014-03	Tan	1849	13.01	10.53%	7	19.6%	0.0244			10YR 7/1	Medium	Sub-rounded				
0039-01	Gray	9999	8.1	12.35%	6	16.7%	0.0216	1.68		Gley1 8/N	Coarse	Sub-rounded	3	220	3	2
0039-03	DkTan	9999	13.07	8.19%	7	15.3%	0.0145			7.5YR 6/2	Coarse	Rounded	2	120	2	1
0044-01	Gray	1851	15.4	9.74%	6	25.0%	0.0097	2.71	Aluminum pan discolor	Gley1 7/N	Coarse	Sub-rounded	4	120	3	3
0045-01	Tan	1834	13.8	13.04%	10	18.0%	0.0236	3.52		10YR 8/1	V Coarse	Sub-rounded	3	80	2	1
0053-02	DkTan	1816	15.52	11.79%	8	22.9%	0.0216			7.5YR 6/2	Medium	Sub-rounded				
0067-01	Tan	1849	17.1	12.28%	8	26.3%	0.0307	2.89	Aluminum pan discolor	10YR 8/1	Medium	Sub-angular				
0089-02	DkTan-SF	1922	15.3	8.50%	10	13.0%	0.0098	3.35		10YR 6/2	Coarse	Sub-angular				
0089-06	DkTan	1922	18.53	11.87%	10	22.0%	0.0138			10YR 6/2	Coarse	Sub-angular	3.5	120	2	2
0107-03	DkTan	1867	12.2	9.02%	8	13.8%	0.0102	2.64	Sl. Discoloration	10YR 6/2	Coarse	Sub-angular	3	220	2	2
0120-02	DkTan	1812	13.1	9.55%	5	25.0%	0.0126			Mixed	Medium	Sub-rounded	3.5	120	2	3
0120-02a	DkTan-SF-Gr	1812	24.9	8.03%	14	14.3%	0.0120	4.04	Sl. Discoloration	Gley1 7/N	Medium	Rounded	3.5	120	2	3
0120-02b	DkTan-SF	1812	11.3	7.96%	6	15.0%	0.0111	3.65	Sl. Discoloration	10YR 6/2	Coarse	Sub-rounded	3.5	120	2	3
0143-01	DkTan	1814	21.2	8.02%	12	14.2%	0.0153	4.22		10YR 6/2	Coarse	Sub-rounded				
0146-03	Tan-Gr	1835	18.52	10.91%	10	20.2%	0.0150		Sl. Disaggregation	10YR 8/1	Medium	Sub-rounded				
0146-05	Gray	1835	4.16	7.69%	2	21.3%	0.0180			Gley1 7/N	Medium	Sub-angular	4	80	2	3
0146-06	Tan	1835	17.04	8.63%	9	16.3%	0.0126		Sl. Disaggregation	10YR 8/1	Medium	Sub-rounded	3	220	2	3
0200-01	DkTan-Gr	1822	21.4	7.01%	11	13.6%	0.0093	4.02		Gley1 7/N	Medium	Sub-rounded				
0200-03	White	1822	17.7	18.08%	12	26.7%	0.0268	5.21		7.5YR 7/2	Medium	Rounded	3	320	1	1
0200-04	DkTan	1822	18.48	10.61%	10	19.6%	0.0179			10YR 6/2	Medium	Sub-rounded	3.5	80	2	2
0200-05	Gray	1822	15.38	6.18%	5	19.0%	0.0054			Gley1 7/N	Medium	Sub-angular	3.5	120	3	3
0203-01	Tan-SF	1831	12.8	9.37%	8	15.0%	0.0137	4.11	Sl. Discoloration	10YR 6/2	Medium	Sub-angular				
0207-01	Tan-SF	1853	9.8	11.22%	6	18.3%	0.0204	3.29		10YR 7/2	Coarse	Sub-rounded				
0208-02	SF-Gray	1868	5.0	2.00%	4	2.5%	0.0150	1.22		Gley1 7/N	Coarse	Rounded				
0208-03	Tan	1868	13.5	17.04%	8	28.8%	0.0333	6.36		10YR 7/2	Medium	Sub-rounded				
0209-01	Tan	9999	9.2	8.70%	6	13.3%	0.0163	2.29	Disaggregation	7.5YR 7/1	Medium	Sub-rounded				
0210-01	Tan	1858	3.9	10.26%	2	20.0%	0.0256	1.36	Sl. Discoloration, Disagg	10YR 7/2	Coarse	Sub-rounded				

Total Immersion - Stucco, 1 of 4

Table 9 - Total Immersion Tests on Stucco

Sorted by Tomb Number

Sample	Stucco Type	First Date	Mo Dry Weight	Msat %	Va ml Displ	% Porosity	Init. Slope	Thick	Comments-End	Color	Texture	Aggregate	Mohs Hardness	Texture Grit	Grind Diff	Ease to Break
0226-01	DkTan-Gr	1806	16.9	9.47%	10	16.0%	0.0133	2.81	Sl. Disagg. and Discol.	10YR 6/2	Medium	Sub-rounded	4	120	3	3
0226-02	Gray	1806	6.0	6.67%	4	10.0%	0.0083	1.67	Sl. Discoloration	7.5YR 6/1	Coarse	Sub-rounded	2.5	220	2	1
0226-03	DkTan	1806	18.8	12.41%	10	23.3%	0.0168			10YR 6/2	Coarse	Sub-angular	4	120	3	3
0227-01	Tan-SF	9999	11.8	10.17%	7	17.1%	0.0169	2.37		10YR 7/3	Medium	Sub-rounded				
0228-01	Tan	1803	13.7	11.68%	8	20.0%	0.0255	3.80	Sl. Discoloration	7.5YR 7/2	Medium	Rounded				
0231-01	DkTan	1947	9.1	7.69%	5	14.0%	0.0110	2.23	Sl. Discoloration	10YR 6/2	Coarse	Sub-rounded				
0237-01	Tan	9999	18.7	10.70%	10	20.0%	0.0241	3.45		10YR 7/2	Coarse	Sub-rounded				
0239-01	Tan	1854	11.2	13.39%	7	21.4%	0.0134	3.91		7.5YR 7/2	Coarse	Sub-rounded	3	120	2	3
0244-01	DkTan	9999	15.9	10.69%	9	18.9%	0.0110	2.92	Sl. Disaggregation	10YR 6/2	Coarse	Sub-rounded				
0244-02	DkTan-Gr	9999	11.5	6.96%	6	13.3%	0.0087	2.64	Sl. Discoloration	Gley1 6/N	Coarse	Sub-rounded				
0251-05	Tan	1826	13.5	11.11%	7	21.4%	0.0204	3.23	Sl. Disaggregation	10YR 7/2	Medium	Sub-rounded				
0253-01	Gray-SF	1835	5.5	7.27%	2	20.0%	0.0091	3.10		10YR 6/1	Coarse	Sub-rounded	3	220	2	3
0254-01	Tan-SF	9999	10.0	7.00%	6	11.7%	0.0150	2.67	Sl. Discoloration, Disagg	10YR 7/2	Coarse	Sub-rounded				
0259-04	White	1823	9.9	11.11%	5	22.0%	0.0202	2.09		White	V. Coarse	Sub-rounded	2.5	50	1	0
0260-01	Tan-SF	1877	10.1	10.89%	6	18.3%	0.0223	1.83		10YR 7/2	Medium	Sub-rounded				
0263-01	Tan	1853	7.0	14.29%	4	25.0%	0.0286	1.07		10YR 7/3	Medium	Rounded				
0267-01	Tan-SF	1853	17.9	10.61%	11	17.3%	0.0223	3.42		7.5YR 8/1	Coarse	Rounded				
0272-01	Tan	9999	13.1	9.92%	8	16.3%	0.0191	2.47		10YR 7/2	Coarse	Sub-rounded				
0275-01	Gray	1851	15.7	8.92%	9	15.6%	0.0096	2.08	Aluminum pan discolor	White	Medium	Rounded				
0291-01	DkTan-SF	1927	13.6	7.35%	9	11.1%	0.0092	3.33		10YR 6/2	Coarse	Sub-rounded	3	220	3	3
0298-01	Tan	1852	7.7	11.69%	4	22.5%	0.0227	1.54		10YR 8/2	Medium	Sub-rounded	4	120	2	3
0313-01	DkTan-SF	1853	21.5	10.23%	12	18.3%	0.0081	6.13		7.5YR 6/2	Medium	Rounded				
0313-02	Tan	1853	20.3	19.21%	14	27.9%	0.0222	7.57	Sl. Discoloration	10YR 7/2	Medium	Sub-angular				
0330-01	DkTan	1853	4.5	11.11%	2	25.0%	0.0222	1.78	Sl. Disaggregation	10YR 6/3	Medium	Sub-angular				
0334-01	Tan-SF-Gr	1838	14.7	12.24%	7	25.7%	0.0187	3.08		10YR 7/1	Medium	Sub-rounded				
0334-03	Tan	1838	14.3	11.19%	8	20.0%	0.0140	3.40		10YR 7/2	Coarse	Sub-rounded				
0373-01	Tan-Gr-SF	1920	20.2	12.87%	11	23.6%	0.0210	4.25	Aluminum pan discolor	7.5YR 8/1	Coarse	Sub-rounded				
0373-02	SF-Gray	1920	5.5	7.27%	2	20.0%	0.0045	1.32	Aluminum pan discolor	Gley1 8/N	Coarse	Rounded				
0373-03	Tan-SF	1920	4.3	16.28%	2	35.0%	0.0349	2.77		10YR 7/1	Medium	Sub-angular				
0381-01	Tan	9999	14.7	10.88%	7	22.9%	0.0136	4.11		10YR 8/2	Coarse	Sub-rounded				
0383-01	Tan	1924	10.1	10.89%	5	22.0%	0.0149	3.87		10YR 8/1	Medium	Sub-rounded				
0401-02	Tan	9999	9.3	9.68%	5	18.0%	0.0215	2.24		10YR 7/1	Coarse	Sub-rounded				
0425-01	Tan	1842	18.59	9.36%	11	15.8%	0.0210			10YR 7/2	Medium	Sub-rounded				
0430-01	Tan	1853	12.04	7.14%	6	14.3%	0.0168			7.5YR 8/1	Medium	Sub-rounded				
0430-02	DkTan	1853	13.37	10.99%	7	21.0%	0.0136			10YR 6/2	Medium	Sub-angular				
0439-01	DkTan-SF	9999	8.3	7.23%	4	15.0%	0.0151	1.67	Sl. Disaggregation	10YR 6/3	Coarse	Sub-angular				
0469-01	DkTan	1816	15.82	9.29%	9	16.3%	0.0180			10YR 7/2	Medium	Sub-angular				
0487-01	DkTan	1838	12.86	9.95%	8	16.0%	0.0154			10YR 7/2	Medium	Sub-angular				

Total Immersion - Stucco, 2 of 4

Table 9 - Total Immersion Tests on Stucco

Sorted by Tomb Number

Sample	Stucco Type	First Date	Mo Dry Weight	Msat %	Va ml Displ	% Porosity	Init. Slope	Thick	Comments-End	Color	Texture	Aggregate	Mohs Hardness	Texture Grit	Grind Diff	Ease to Break
0493-01	Tan	1879	12 85	8 56%	5	22.0%	0.0167			10YR 8/2	Medium	Sub-rounded				
0503-01	Tan-SF	1848	19 0	8 42%	10	16 0%	0 0105	3 54		7 5YR 8/1	Medium	Sub-rounded				
0505-01	Tan	9999	12 2	11.48%	7	20 0%	0 0143	3 33	Sl. Discoloration	7 5YR 8/1	Medium	Sub-rounded				
0508-01	DkTan-SF	1853	16 0	10 00%	10	16.0%	0 0188	4 45	Sl. Discoloration	7.5YR 7/2	Coarse	Rounded	4	120	2	3
0508-01	DkTan	1853	24 45	8 83%	14	15.4%	0 0164			10YR 7/2	Coarse	Sub-angular				
0518-01	DkTan	1887	10 9	11 01%	7	17.1%	0 0138	3 34		7.5YR 7/2	Coarse	Rounded				
0522-01	Tan	1851	30 5	15 08%	20	23 0%	0 0287	6 49	Disaggregation	10YR 7/2	Coarse	Sub-rounded				
0522-04	DkTan-SF	1851	6 9	10 14%	3	23.3%	0.0181	2.35		10YR 7/2	Coarse	Sub-rounded				
0525-01	DkTan-Gr-SF	1851	9 2	5 43%	6	8 3%	0 0163	1 89	Sl. Disaggregation	10YR 7/2	Coarse	Sub-rounded				
0525-01	DkTan	1851	14 35	9 27%	9	14 8%	0 0176			10YR 7/2	Coarse	Sub-angular				
0540-01	Tan-SF	1920	23 6	9 75%	12	19 2%	0.0106	3 52		10YR 8/1	Coarse	Rounded				
0541-01	DkTan-SF	9999	8 4	9 52%	4	20 0%	0 0119	1.76		10YR 7/1	Medium	Sub-angular				
0544-02	Tan-SF	9999	15 2	16 45%	10	25 0%	0 0132	3 35		10YR 7/2	Medium	Sub-rounded				
0544-03	Tan	9999	9 7	11 34%	3	36 7%	0 0129	2.90	Sl Discoloration	10YR 6/2	Coarse	Sub-rounded				
0545-01	Tan-SF	9999	10 3	9 71%	5	20 0%	0 0218	3 94	Sl. Disaggregation	10YR 8/1	Medium	Sub-angular				
0548-02	Tan-SF	1820	15 2	11 84%	9	20 0%	0.0181	2 71		10YR 8/1	Medium	Sub-rounded	3	80	2	2
0549-01	Tan-SF	1923	11 5	9 57%	4	27.5%	0 0130	2 92		Gley1 8/N	Coarse	Sub-rounded	3	220	2	2
0550-01	DkTan	1866	11 2	6.25%	5	14.0%	0 0089	2 46	Sl. Discoloration	7.5YR 6/2	Medium	Sub-rounded				
0551-01	Gray-SF	9999	14 6	4 79%	6	11 7%	0.0034	2 55		10YR 6/1	Medium	Sub-rounded	4	220	3	3
0552-01	Gray-SF	1804	6 6	9 09%	3	20 0%	0 0038	1.64		10YR 6/1	Fine	Sub-angular				
0552-02	Tan	1804	6.8	10 29%	3	23 3%	0.0184	1.88		10YR 7/2	Coarse	Sub-rounded				
0558-04	DkTan-SF	9999	17 5	9 71%	10	17 0%	0 0129	3 26		10YR 7/2	Medium	Sub-rounded	3	320	2	3
0558-05	Tan-SF	9999	14 3	13 99%	8	25 0%	0 0297	3 48	Discoloration	10YR 7/2	Coarse	Sub-rounded	3	120	1	2
0558-07	Gray	9999	15 6	9 62%	8	18.8%	0.0144		Alum pan discolor, scum	Gley1 8/N	Coarse	Rounded	3 5	80	3	3
0562-01	DkTan	1929	9 6	7.29%	5	14.0%	0.0130	2.33		10YR 6/2	Medium	Sub-rounded				
0562-02	Tan-SF	1929	6 8	13 24%	3	30 0%	0 0257	1 68		10YR 6/2	Medium	Sub-rounded				
0563-01	Tan-SF	1824	9 8	11 22%	6	18 3%	0 0204	2 18	Sl. Discoloration	10YR 7/2	Coarse	Sub-rounded				
0564-01	Tan	9999	11.7	10 26%	5	24 0%	0 0214	2 05		10YR 8/2	Coarse	Sub-rounded				
0564-02	Tan-SF	9999	7 9	7 59%	2	30.0%	0.0063	1 50		White	Medium	Sub-rounded				
0565-01	DkTan-SF	9999	13	6 15%	6	13 3%	0 0077	2.24		7.5YR 7/2	Medium	Sub-rounded				
0573-03	DkTan	1853	11 7	12 82%	5	30 0%	0 0256	3 35		10YR 7/2	Coarse	Sub-rounded	3	120	2	2
0577-01	Tan-SF	1819	9 3	10 75%	3	33 3%	0 0188	1 67		7 5YR 7/2	Coarse	Rounded				
0577-02	Gray	1819	5 3	5 66%	2	15 0%	0 0094	6 80	Sl Disaggregation	7 5YR 7/1	Medium	Sub-angular				
0577-04	DkTan	1819	27 4	8 03%	14	15.7%	0 0091	3 84	Discoloration	10YR 6/2	Coarse	Sub-rounded				
0579-01	Tan	9999	12 4	10 48%	5	26 0%	0 0222	1.94	Sl. Discoloration	10YR 8/2	Medium	Rounded	3	220	1	1
0579-05	Tan	9999	17 53	14 15%	8	31 0%	0 0299			10YR 7/1	Medium	Sub-rounded	3	220	1	1
0581-01	Gray	9999	8 7	8 05%	5	14 0%	0 0115	1 65	Pan discolor, Sl Disagg	Gley1 8/N	V Coarse	Sub-rounded	4	120	3	2
0582-01	Tan-SF	1859	11 4	9 65%	6	18 3%	0 0154	2 24		10YR 7/2	Medium	Sub-rounded				

Total Immersion - Stucco, 3 of 4

Table 9 - Total Immersion Tests on Stucco

Sorted by Tomb Number

Sample	Stucco Type	First Date	Mo Dry Weight	Msat %	Va ml Displ	% Porosity	Init. Slope	Thick	Comments-End	Color	Texture	Aggregate	Mohs Hardness	Texture Grit	Grind Diff	Ease to Break
0582-01	Tan	1859	19 56	12 93%	10	25 3%	0 0116			10YR 7/1	Medium	Sub-rounded				
0593-03	Tan-SF	9999	8 5	15 29%	3	43 3%	0 0324	2.31	Sl Disaggregation	10YR 7/2	Coarse	Sub-rounded				
0593-04	Tan	9999	6.7	13 43%	4	22.5%	0 0299	2.46		10YR 7/2	Coarse	Sub-rounded				
0596-01	Tan	1822	9 5	10 53%	4	25 0%	0 0211	2 54		10YR 7/2	Medium	Rounded				
0597-01	Tan-Gr	1858	11 6	12 07%	6	23.3%	0 0237	4.13		7 5YR 8/2	Coarse	Sub-rounded				
0600-02	Tan-Gr	1824	10.7	11 21%	6	20 0%	0 0210	2 28		10YR 6/2	Coarse	Sub-rounded				
0600-04	Tan	1824	21 15	12 91%	12	22 8%	0 0234			7 5YR 6/3	Coarse	Sub-rounded	3	120	2	2
0601-02	Tan	9999	20 7	13 04%	12	22 5%	0 0157	4 11	Discoloration	10YR 7/2	Coarse	Sub-rounded				
0601-03	Gray	9999	6 5	7 69%	2	25 0%	0 0115	2 22		10YR 7/1	Medium	Sub-rounded				
0602-02	Gray	9999	17 35	12 51%	10	21.7%	0 0232			Gley1 8/N	Medium	Sub-angular				
0612-01	Gray-SF	9999	16 1	6 83%	6	18 3%	0 0093	2.74	Scum, Pan discolor	Gley1 8/N	Medium	Rounded				
0620-01	Tan	1847	23 1	12 99%	12	25 0%	0 0249	4 57	Sl Discoloration	7 5YR 7/2	Medium	Sub-rounded				
1200-01e	Gray	1813	14 30	14 76%	9	23 4%	0 0255			10YR 7/1	Medium	Rounded				
1200-02m	White	1813	11 51	16.94%	8	24 4%	0 0352			10YR 8/1	Fine	Sub-angular	3 5	120	3	3
1200-07e	DkTan	1813	16.91	10 41%	9	19 6%	0 0143			10YR 6/2	Medium	Sub-angular	2 5	600	1	1
1200-08m	White	1813	26 31	28 85%	18	42 2%	0 0578			10YR 8/1	Fine	Rounded	3	80	2	3
1300-01	Gray	1818	29 5	6 78%	16	12 5%	0 0059	1 04	Scum, Pan discolor	10YR 6/1	Coarse	Sub-rounded	2 5	600	1	1
1300-02	Tan-SF	1818	8 3	9 64%	3	26.7%	0 0211	5 35		7 5YR 8/1	Medium	Rounded	4	80	3	3
2005-01	Gray-SF	9999	7 3	9 59%	3	23 3%	0 0103	2 15	Aluminum pan discolor	Gley1 8/N	Medium	Sub-rounded	2 5	320	1	1

Total Immersion - Stucco, 4 of 4

Table 10 - Total Immersion Tests on Mortar

Sorted by Tomb Number

Sample	Stucco Type	First Date	Mo Dry Weight	Msat %	Va ml Displ	% Porosity	Init. Slope	Thick	Comments-End	Color	Texture	Aggregate	Mohs Hardness
0002-03	1921	Mortar	10.80	13 89%	Not tested	Not tested	0 275	N/A	Disaggregation	10YR 8/2	Fine	Sub-rounded	1
0009-03	1822	Mortar	22 00	11 36%	Not tested	Not tested	0.525	N/A		White	Fine	Sub-rounded	1
0013-03	1830	Mortar	11.30	14.16%	Not tested	Not tested	0 275	N/A	Disaggregation	7 5YR 8/1	Fine	Sub-rounded	1
0045-03	1834	Mortar	16 30	30.67%	Not tested	Not tested	1 025	N/A	Sl Disaggregation	7.5YR 8/1	Fine	Sub-rounded	0
0089-05	1922	Mortar	13 70	17 52%	Not tested	Not tested	0 500	N/A	Fine Sands, Disagg	7 5YR 8/2	Fine	Sub-rounded	1
0092-01	1919	Mortar	18 00	32 22%	Not tested	Not tested	1 250	N/A		7.5YR 8/1	Fine	Sub-rounded	0
0107-02	1867	Mortar	24 50	22 04%	Not tested	Not tested	1.175	N/A	Fine Sands, Disagg	10YR 8/2	Fine	Sub-rounded	0
0120-03	1812	Mortar	19 60	32 14%	Not tested	Not tested	1 375	N/A		7 5YR 8/1	Fine	Sub-rounded	1
0146-02	1835	Mortar	14 00	34 29%	Not tested	Not tested	1 025	N/A		7 5YR 8/1	Fine	Sub-rounded	1
0251-02	1826	Mortar	16 20	32.72%	Not tested	Not tested	1 125	N/A	Disaggregation	7 5YR 8/1	Fine	Sub-rounded	0
0259-05	1823	Mortar	15 50	18 06%	Not tested	Not tested	0.450	N/A	Dissolved Surface	White	Fine	Sub-rounded	1
0334-04	1838	Mortar	3 69	30 08%	Not tested	Not tested	0 027	N/A	V Disaggregated	10YR 6/3	Fine	Sub-rounded	0
0487-03	1838	Mortar	5 39	20 59%	Not tested	Not tested	0.145	N/A	V Disaggregated	10YR 7/2	Fine	Sub-rounded	0
0548-03	1820	Mortar	19 80	24 75%	Not tested	Not tested	0 950	N/A	Sl Disaggregation	10YR 7/2	Fine	Sub-rounded	1
0573-02	1853	Mortar	22 10	21 72%	Not tested	Not tested	1 025	N/A	Disaggregation	10YR 8/3	Fine	Sub-rounded	0
0579-04	9999	Mortar	16 20	22 22%	Not tested	Not tested	0.725	N/A	Sl. Disaggregation	White	Fine	Sub-rounded	0
0600-03	1824	Mortar	17 40	31 03%	Not tested	Not tested	1 175	N/A	Sl Disaggregation	10YR 8/1	Fine	Sub-rounded	1
1200-03e	1813	Mortar	15 96	31.70%	Not tested	Not tested	1 030	N/A		10YR 7/4	Fine	Sub-rounded	1
1200-04m	1813	Mortar	11 16	31 63%	Not tested	Not tested	0 705	N/A		7 5YR 8/1	Fine	Sub-rounded	1
1200-09e	1813	Mortar		18 39%	Not tested	Not tested	0 723	N/A		10YR 7/4	Fine	Sub-rounded	1
1200-11e	1813	Mortar	16 30	34 05%	Not tested	Not tested	0 983	N/A		10YR 8/2	Fine	Sub-rounded	2
1200-12m	1813	Mortar	13 81	32 59%	Not tested	Not tested	1 035	N/A		7 5YR 8/1	Fine	Sub-rounded	2

Total Immersion - Mortar, 1 of 1

Table 11 - Total Immersion Tests on Brick
Sorted by Tomb Number

	First		Wet	Munsell	Munsell	Disinteg	Sample	16 days		Va	Porosity
Sample	Date		Color	Exterior	Interior	Rating	Cut	Msat	Mp, Vp	ml Displ	
0009-04	1822	Platform	O-Red	10YR 6/1	2.5 YR 5/6	3	Avg.	23.27%	53.00	133.3	39.73%
0013-01	1830	Platform	Red	2.5 YR 7/3	10 R 6/4	4	Avg.	17.43%	30.47	116.7	26.11%
0045-01	1834	Parapet	DkO-Red	2.5 YR 5/8	2.5 YR 5/8	4	Avg.	22.53%	47.45	120.0	39.84%
0089-03	1922	Platform	Tan	10 YR 7/1	7.5 YR 8/2	2	Avg.	18.16%	39.09	126.7	32.15%
0089-04	1922	Platform	O-Red	2.5 YR 5/3	2.5 YR 5/3	4	Avg.	22.66%	50.29	150.0	33.53%
0092-02	1919	Step	DkRed	5 YR 6/3	5 YR 5/2	1	Avg.	10.09%	14.10	91.7	15.35%
0107-01	1867	Parapet	DkO-Red	2.5 YR 5/6	2.5 YR 5/8	5	Avg.	24.91%	37.08	95.0	39.02%
0120-02	1812	Parapet	Orange	5 YR 6/2	7.5 YR 7/4	3	Avg.	16.34%	23.09	85.0	27.51%
0146-01	1835	Platform	Pink-Red	5 YR 7/1	5 YR 7/3	2	Avg.	17.01%	34.24	125.0	27.37%
0251-01	1826	Platform	O-Red	5 YR 6/8	5 YR 6/8	5	Avg.	24.39%	34.37	88.3	39.80%
0259-01	1823	Platform	O-Red	2.5 YR 6/6	2.5 YR 6/6	5	Avg.	21.66%	21.74	60.0	36.53%
0259-02	1824	Platform	O-Red	5 YR 6/6	5 YR 6/8	4	Avg.	24.26%	32.71	88.3	38.16%
0334-01	1838	Parapet	Red	5 YR 6/1	10 R 6/6	3	Avg.	17.14%	30.65	108.3	28.18%
0487-01	1838	Platform	O-Tan	7.5 YR 7/2	7.5 YR 7/4	2	Avg.	18.65%	28.82	106.7	26.96%
0548-01	1820	Parapet	Pink-Red	7.5 YR 7/2	5 YR 6/4	3	Avg.	15.16%	30.93	130.0	25.69%
0558-01	9999	Platform	Pink-Red	7.5 YR 7/2	7.5 YR 6/4	3	Avg.	19.21%	43.70	155.0	28.22%
0558-02	9999	Platform	Orange	10 YR 8/4	10 YR 8/4	4	Avg.	16.64%	30.31	110.0	27.74%
0558-03	9999	Platform	Orange	2.5 YR 6/6	2.5 YR 6/8	4	Avg.	21.27%	40.14	106.7	37.07%
0573-01	1853	Parapet	O-Tan	10 YR 7/4	10 YR 8/4	2	Avg.	17.56%	37.42	116.7	32.09%
0579-02	9999	Parapet	O-Red	5 YR 6/6	5 YR 6/8	4	Avg.	20.25%	44.51	126.7	37.00%
0579-03	9999	Parapet	O-Red	5 YR 6/6	5 YR 6/8	4	Avg.	21.63%	40.76	118.3	34.81%
0593-02	9999	Platform	O-Tan	7.5 YR 7/2	7.5 YR 7/4	2	Avg.	21.53%	46.25	120.0	38.50%
1200-05	1813	Wall Vault	DkO-Red	2.5 YR 5/6	2.5 YR 5/6	5+	Avg.	22.28%	35.19	103.3	33.89%
1200-06	1813	Wall Vault	O-Red	5 YR 5/4	5 YR 5/4	3	Avg.	13.76%	23.07	88.3	26.49%

Table 12 - Final Testing Plan - St. Louis Cemetery No. 1

<table>
<tr><td colspan="7">Stucco H_2O Total Immersion, % Porosity
119 Stucco Samples, 89 Tombs Tested</td></tr>
<tr><td colspan="7">Brick H_2O Total Immersion, % Porosity, Salt Identification
24 Bricks, 72 Samples (3/brick), 18 Tombs</td></tr>
<tr><td colspan="7">Mortar H_2O Total Immersion, % Porosity
20 Mortar Samples, 17 Tombs Tested</td></tr>
<tr><th>None</th><th>White</th><th>Tan</th><th>Dk Tan</th><th>Gray</th><th>ComboT</th><th>ComboDk</th></tr>
<tr><td colspan="7">Capillary Absorption, Drying Curves & MVT, 35 Stucco Samples Tested</td></tr>
<tr><td>N/A</td><td>200-03
259-04</td><td>45-01
548-02/x
579-05
239-02</td><td>04-01
89-02/x
291-02
573-03
550-01
508-01
226-03</td><td>44-01
551-01
581-01
275-02
200-05
602-02</td><td>146-03
600-02/04
9-04/07/08
02-01/05
146-03</td><td>120-02
200-01/04
04-01
39-03/04</td></tr>
<tr><td colspan="7">Stucco Gravimetric/Acid Digestion and Salt Identification, 30 Samples Analyzed</td></tr>
<tr><td>N/A</td><td>200-03
259-04
1200M-02
1200M-08
1200E-11</td><td>45-01
548-02
13-01
1200-09</td><td>89-02
573-03
107-01</td><td>44-01
581-01
1300-01
275-02
602-02</td><td>600-04/05
9-07/08
14-01/02</td><td>39-01/02
200-
01/05
558-
04/5/7</td></tr>
<tr><td colspan="7">Mortar Gravimetric/Acid Digestion and Salt Identification – 20 Analyzed</td></tr>
<tr><td colspan="7">Capillary Absorption, Drying Curves & MVT 17 Brick w/ Stucco Samples Tested
R = River Brick, L = Lake Brick</td></tr>
<tr><td>N/A</td><td>R: 259-01
R: 259-02</td><td>L: 013-01
R: 251-01
L: 548-01
R: 579-03
L: 593-04
R: 045-02</td><td>R: 089-04
R: 107-01
L: 573-01</td><td>None</td><td>R: 009-04
L: 146-01
L: 334-01</td><td>L: 120-01
L: 558-01
L: 558-02</td></tr>
<tr><td colspan="7">Capillary Absorption, Drying Curves & MVT 14 Brick w/o Stucco Samples Tested
R = River Brick, L = Lake Brick</td></tr>
<tr><td>92-02x</td><td>R: 259-01x</td><td>L: 013-01x
L: 548-01x
R: 579-03x
L: 593-04x</td><td>R:089-04x
L: 573-01x</td><td>None</td><td>R: 009-04x
L: 146-01x</td><td>L: 120-
01x
R: 558-
03x</td></tr>
<tr><td colspan="7">Reflected Light Microscopy – Matrix Porosity & Interface Analysis - Thick Sections</td></tr>
<tr><td></td><td>1200-08</td><td>548-02</td><td>89-02</td><td></td><td>9-07, 08</td><td>39-01, 02</td></tr>
<tr><td colspan="7">Polarized Light Microscopy – Mineral ID and Thin Section of all layers</td></tr>
<tr><td></td><td>1200-08
200-03</td><td>45-01</td><td>89-05</td><td>581-01</td><td>9-04, 03
600-04/05</td><td></td></tr>
</table>

Table 13 - Stucco Water Vapor Transmission Test Data
Calculated Values are Shaded in Green

			7-Day WVT						
Stucco	Stucco	Surface	t	G	cm	A	Sample	$g/hr*cm^2$	$g/day*m^2$
Samples	Type	Finish	Time hrs.	Wt. Change	Thick	Test Area	Diameter	WVT	WVT
0551-01	Gray	SF	168	0.35	0.692	21.23	5.2	0.00010	23.56
0002-01	Tan-Gr	SF	168	0.58	2.510	22.89	5.4	0.00015	36.20
0548-02	Tan	SF	168	1.64	0.790	22.05	5.2	0.00044	106.25
0004-01	DkTan	SF	168	1.84	3.250	22.05	5.3	0.00050	119.21
0550-01	DkTan	SF	168	1.95	3.370	22.05	5.3	0.00053	126.33
0089-02	Dk Tan	SF	168	1.95	0.709	20.42	5.1	0.00057	136.44
0579-05	Tan	SF	168	2.13	3.630	21.23	5.2	0.00060	143.35
0508-01	Dk Tan	SF	168	2.39	4.030	21.23	5.2	0.00067	160.85
0275-02	White Gr		168	0.48	3.030	22.05	5.3	0.00013	31.10
0009-04	Tan-Gr		168	0.52	1.397	22.89	5.4	0.00014	32.45
0044-01	Gray		168	0.49	3.130	20.42	5.2	0.00014	32.98
0009-07	Gray		168	0.56	2.650	22.05	5.3	0.00015	36.28
0200-05	Gray		168	0.63	3.070	22.05	5.3	0.00017	40.82
0581-01	Gray		168	0.73	1.530	21.23	5.2	0.00020	49.13
0600-02	Tan-Gr		168	0.91	1.135	22.05	5.3	0.00025	58.96
0120-02	DkTan-Gr		168	1.42	1.035	21.23	5.2	0.00040	95.57
0573-03	Dk Tan		168	1.64	1.187	21.23	5.2	0.00046	110.37
0200-03	White		168	1.73	0.798	22.05	5.3	0.00047	112.08
0259-04	White		168	1.76	0.907	21.23	5.1	0.00051	123.14
0239-02	Tan		168	1.81	4.270	21.23	5.2	0.00051	121.82
0291-02	Dk Tan		168	1.90	4.090	22.05	5.3	0.00051	123.09
0039-04	Gray		168	2.01	2.320	22.05	5.3	0.00054	130.22
0089-X	Dk Tan		168	1.99	4.130	21.23	5.2	0.00056	133.93
0602-02	White Gr		168	2.23	3.620	22.05	5.3	0.00060	144.47
0200-01	DkTan-Gr		168	2.07	1.030	20.42	5.1	0.00060	144.83
0200-04	Dk Tan		168	2.28	3.190	21.23	5.2	0.00064	153.45
0146-03	Tan-Gr		168	2.35	3.310	20.42	5.1	0.00069	164.42
0548-04X	Tan		168	2.45	2.780	21.23	5.2	0.00069	164.89
0045-01	Tan		168	2.46	0.902	21.23	5.2	0.00069	165.56
0002-05	White Gr		168	2.63	4.310	22.05	5.3	0.00071	170.39
0039-03	Tan		168	3.07	1.960	22.05	5.3	0.00083	198.89
0226-03	Dk Tan		168	3.03	2.750	21.23	5.2	0.00085	203.92
0600-04	Tan		168	3.92	2.670	22.05	5.3	0.00106	253.96

Table 14 - Brick Water Vapor Transmission Test Data

Calculated Values are Shaded in Green

		7-day MVT		A	WVT	WVT	cm.	Sample
Brick Samples		Time hrs.	Wt. Change	Test Area	g/hr*cm2	g/day*m2	Thickness	Sample
0092-02X	Imported	168	1.01	6.00	0.0010	240.48	1.9	Bare Brick
0120-01	Lake	168	0.70	6.00	0.0007	166.67	1.9	Brick w/ Stucco
0013-01	Lake	168	0.74	6.00	0.0007	176.19	1.9	Brick w/ Stucco
0548-01	Lake	168	0.84	5.75	0.0009	208.70	1.9	Brick w/ Stucco
0334-01	Lake	168	1.51	7.28	0.0012	296.31	1.9	Brick w/ Stucco
0089-03	Lake	168	1.55	6.50	0.0014	340.66	1.9	Brick w/ Stucco
0579-02	Lake	168	1.69	5.52	0.0018	437.37	1.9	Brick w/ Stucco
0573-01	Lake	168	1.37	5.52	0.0015	354.55	1.9	Brick w/ Stucco
0558-02	Lake	168	1.72	5.52	0.0019	445.13	1.9	Brick w/ Stucco
0593-02	Lake	168	1.90	6.00	0.0019	452.38	1.9	Brick w/ Stucco
0146-01	Lake	168	1.84	5.29	0.0021	496.89	1.8	Brick w/ Stucco
1200-06X	Lake	168	1.76	5.98	0.0018	420.45	1.9	Bare Brick
0573-01X	Lake	168	2.30	5.50	0.0025	597.40	1.9	Bare Brick
0548-01X	Lake	168	2.27	5.28	0.0026	614.18	1.9	Bare Brick
0120-01X	Lake	168	2.59	6.00	0.0026	616.67	1.9	Bare Brick
0146-01X	Lake	168	2.49	5.76	0.0026	617.56	1.9	Bare Brick
0013-01X	Lake	168	3.25	6.25	0.0031	742.86	1.8	Bare Brick
0259-02	River	168	1.16	6.50	0.0011	254.95	1.8	Brick w/ Stucco
0259-01	River	168	1.27	5.52	0.0014	328.67	1.8	Brick w/ Stucco
0579-03	River	168	1.40	5.50	0.0015	363.64	1.9	Brick w/ Stucco
0251-01	River	168	1.51	5.52	0.0016	390.79	1.8	Brick w/ Stucco
0045-02	River	168	1.85	6.76	0.0016	390.96	1.8	Brick w/ Stucco
0107-01	River	168	1.67	6.00	0.0017	397.62	1.9	Brick w/ Stucco
0089-04	River	168	1.98	7.02	0.0017	402.93	1.8	Brick w/ Stucco
0009-04	River	168	1.76	5.29	0.0020	475.29	1.9	Brick w/ Stucco
1200-05X	River	168	2.50	6.25	0.0024	571.43	2.2	Bare Brick
0579-03X	River	168	2.70	6.00	0.0027	642.86	1.8	Bare Brick
0259-01X	River	168	3.05	6.00	0.0030	726.19	1.9	Bare Brick
0089-04X	River	168	2.33	4.41	0.0031	754.78	1.8	Bare Brick
0009-04X	River	168	2.86	5.29	0.0032	772.35	1.9	Bare Brick
0558-03X	River	168	2.97	5.29	0.0033	802.05	1.9	Bare Brick

ARCHITECTURAL CONSERVATION LABORATORY
UNIVERSITY OF PENNSYLVANIA

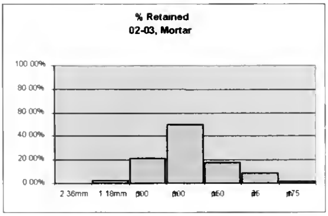
Project/Site: Modeling Decay Mechanisms of Above Ground Tombs at St. Louis Cemetery No. 1, Thesis – J. Peters, August 2002

Description of Sample

Sample Identification: 02-03M	
Type/Location: Bedding Mortar	
Surface appearance: Chalky, soft, breaks easy.	
Cross section: None prepared	
Color: 10YR 7/3	**Texture:** Soft, chalky
Hardness: Very easy (0)	**Gross weight:** 10.51

Components

Fines:	**Color:**	**Wgt:** 1.74	**Wgt. %:** 16.56
	Organic matter: None detected		
	Composition:		
Acid Soluble Fraction: Reaction 0-3, 3=Most Aggressive Foam 0-3, 3=Lg Bubbles, long lasting, 0=Small bubbles, or minimal foam, short lasting.	**Wgt:** 2.05	**Wgt. %:** 19.51	
	Reaction: 2	**Foam size:** 3	
	Filtrate color: Light Yellow	**Composition:** Not analyzed chemically	
Aggregate:	**Color:**	**Wgt:** 6.72	**Wgt. %:** 63.94
	Grain shape: Sub-rounded		
	Mineralogy: Mostly quartz, small bits of brick		



Screen size:	% Retained	Comment:
2.36 mm	0.00%	Fully digested
1.18 mm	2.19%	Rounded, sub-rounded
600 µm	20.76%	Rounded, sub-rounded
300 µm	49.56%	Rounded, sub-rounded
150 µm	17.25%	Bits of shell, sub-round
75 µm	8.19%	Bits of shell, sub-round
Pan <75 µm	2.05%	Added to fines weight

Mortar type: Regular category (not the "Shell" category)

By Weight - Fines : Acid Soluble : Aggregate: ~3.5 : 3 : 10

Gravimetric Analysis of Aggregate after Acid Digestion
Reflected Light, Nikon SMZ-U Microscope, Nikon AFX II A Camera, Fuji 100 ASA, 35 mm Film, Magnification = 5X

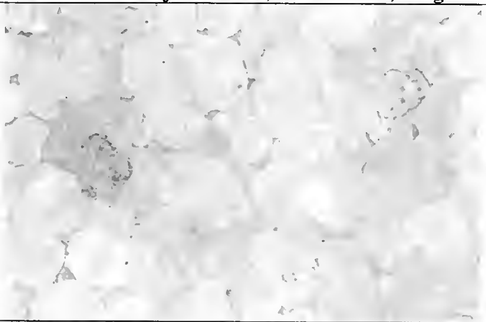
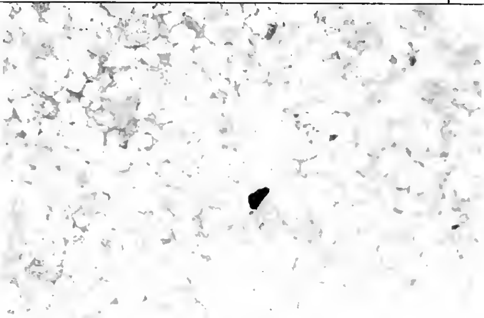
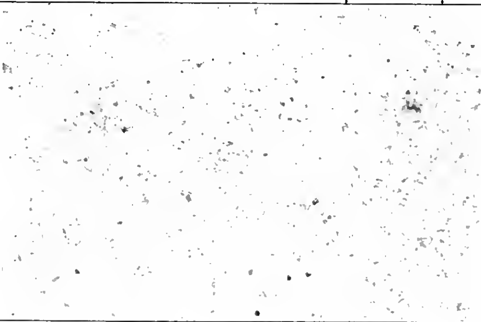
		Mostly rounded aggregate, brick particles evident.
02-03, Mortar	1.18 mm & 600 μm	Fraction 2 & 3
		Mostly rounded aggregate, brick particles evident, black particles.
02-03, Mortar	300 μm & 150 μm	Fraction 4 & 5
		Mostly rounded aggregate, brick particles evident, black particles
02-03, Mortar	75 μm & <75 μm	Fraction 6 & 7

Table 15 - Stucco Gravimetric Analysis - Summary Results

Sorted by Stucco Group

Color	Color	Sample	Fines %	Agg. %	Acid Sol %	Fine+AS / Agg.	Sieve - 1	Sieve - 2	Sieve - 3	Sieve - 4	Sieve - 5	Sieve - 6	Sieve - 7
White	1	200-03	15.62%	25.74%	58.65%	2.89	4.87%	12.87%	18.25%	36.51%	15.05%	6.84%	5.60%
White	1	259-04	4.35%	41.22%	54.43%	1.43	0.12%	0.27%	2.08%	77.33%	16.53%	3.04%	0.65%
White	1	1200-02	6.81%	11.15%	82.04%	7.97	0.32%	0.96%	22.51%	43.09%	22.83%	7.72%	2.57%
White	1	1200-08M	7.50%	5.58%	86.92%	16.93	3.03%	2.02%	8.08%	41.92%	33.33%	10.10%	1.52%
Tan	2	45-01	12.11%	41.19%	46.70%	1.43	0.06%	3.90%	26.63%	30.41%	27.61%	10.05%	1.34%
Tan	2	548-02	10.23%	52.50%	37.27%	0.90	0.04%	0.26%	13.63%	74.68%	8.56%	2.12%	0.71%
Tan	2	13-01	14.12%	53.60%	32.28%	0.87	0.00%	1.30%	10.73%	64.47%	20.46%	2.44%	0.61%
ComboT	2	1200-07E	19.53%	52.94%	27.53%	0.89	0.00%	3.96%	28.45%	51.32%	11.14%	3.67%	1.47%
ComboT	2	558-05	17.31%	55.57%	27.13%	0.80	0.00%	0.19%	1.80%	71.86%	20.03%	3.54%	2.58%
ComboT	2	600-CT	10.70%	61.90%	27.40%	0.62	0.11%	0.58%	16.81%	70.75%	8.04%	2.52%	1.21%
ComboT	2	09-CT	9.73%	59.35%	30.92%	0.68	1.33%	2.16%	23.93%	61.43%	7.88%	2.49%	0.79%
ComboT	2	14-CT	11.24%	60.82%	27.94%	0.64	0.07%	0.27%	8.53%	73.52%	12.42%	3.82%	1.37%
DkTan	3	107-03	12.32%	51.28%	36.40%	0.95	0.07%	0.51%	26.36%	60.13%	9.80%	2.54%	0.58%
DkTan	3	89-02	11.24%	55.06%	33.71%	0.82	0.04%	0.56%	18.65%	66.25%	10.30%	3.12%	1.08%
DkTan	3	573-03	10.18%	62.13%	27.69%	0.61	0.04%	0.14%	12.72%	68.08%	14.82%	3.64%	0.56%
ComboDT	3	39-02	16.61%	50.84%	32.56%	0.97	0.00%	2.40%	29.55%	53.75%	9.66%	3.35%	1.28%
ComboDT	3	558-04	9.04%	52.32%	38.64%	0.91	0.00%	3.11%	8.48%	69.00%	14.93%	3.41%	1.08%
ComboDT	3	200-01	18.42%	45.33%	36.25%	1.21	0.69%	7.71%	18.28%	50.69%	17.29%	4.15%	1.19%
Gray	4	44-01	11.98%	62.11%	25.91%	0.61	0.23%	3.27%	8.47%	60.05%	21.14%	4.85%	1.99%
Gray	4	581-01	19.41%	58.05%	22.54%	0.72	0.89%	5.21%	12.49%	63.41%	13.15%	3.95%	0.89%
ComboG	4	1300-01	10.64%	53.77%	35.59%	0.86	0.15%	3.06%	6.58%	42.73%	37.67%	7.66%	2.14%
ComboG	4	39-01	10.32%	55.91%	33.77%	0.79	0.00%	2.98%	10.20%	56.11%	25.96%	4.04%	0.71%
ComboG	4	200-05	12.66%	49.00%	38.34%	1.04	0.00%	2.92%	10.12%	53.75%	26.96%	4.82%	1.42%
ComboG	4	558-07	10.14%	59.56%	30.30%	0.68	1.00%	15.57%	17.26%	48.61%	15.09%	2.04%	0.43%
ComboG	4	600-CG	19.49%	57.09%	23.42%	0.75	0.17%	6.94%	12.19%	39.63%	28.87%	7.37%	4.83%
ComboG	4	09-CG	15.45%	61.65%	22.90%	0.62	0.15%	0.35%	4.02%	63.39%	24.65%	6.50%	0.94%
ComboG	4	14-CG	11.26%	60.84%	27.90%	0.64	0.00%	0.38%	2.54%	56.31%	33.62%	5.56%	1.60%
WGray	5	275-02	8.97%	57.30%	33.73%	0.75	0.00%	3.65%	15.12%	52.57%	23.54%	4.10%	1.04%
WGray	5	602-02	13.23%	45.95%	40.82%	1.18	0.00%	2.52%	9.18%	51.09%	32.40%	3.86%	0.95%
WGray	5	1200-01E	15.08%	46.91%	38.01%	1.13	0.00%	2.16%	15.43%	50.80%	22.59%	7.16%	1.85%

Table 16 - Mortar Gravimetric Analysis - Summary Results

Sample	Munsell		Fines %	Agg. %	Acid Sol %
012-00	10YR 8/3		12.16%	74.68%	13.16%
013-00	10YR 7/1		63.43%	12.84%	23.73%
02-03 Mortar	10YR 7/3		16.56%	63.94%	19.51%
09-03 Mortar	10YR 8/1		9.76%	68.15%	22.09%
107-02 Mortar	10YR 7/3		20.12%	69.70%	10.18%
1200-09E T-Mortar	7.5YR 7/4		36.17%	37.18%	26.65%
1200-11E W-Mortar	10YR 8/2	Shell type	29.75%	17.26%	52.99%
120-03 Mortar	10YR 7/2	Shell type	50.24%	28.84%	20.92%
1200-M Mortar	7.5YR 8/1	Shell type	35.31%	19.50%	45.19%
13-03 Mortar	2.5Y 7/1		7.27%	73.38%	19.35%
146-02 Mortar	2.5Y 8/1	Shell type	41.90%	22.56%	35.53%
251-02 Mortar	10YR 7/2	Shell type	52.62%	22.48%	24.91%
259-05 W-Mortar	10YR 8/1		10.19%	39.32%	50.49%
334-05	10YR 6/3		77.94%	10.02%	12.04%
351-00	10YR 7/3		21.18%	63.33%	15.49%
45-03 Mortar	2.5Y 8/2	Shell type	39.29%	33.92%	26.78%
487-03	10YR 7/2		16.17%	69.82%	14.01%
548-03 Mortar	2.5Y 7/3		40.38%	38.04%	21.59%
573-02 Mortar	7.5YR 8/4		28.07%	63.49%	8.44%
579-04 Mortar	10YR 8/2		11.78%	66.85%	21.36%
600-03 Mortar	7.5YR 7/2	Shell type	35.22%	34.04%	30.74%
89-05 Mortar	10YR 7/3		19.33%	69.42%	11.25%
92-01 Mortar	2.5Y 8/1	Shell type	38.97%	22.69%	38.34%
Averages - All Mortars			31.04%	44.41%	24.55%

Table 17 - Stucco Capillary Absorption
Example Raw Data, Calculated Values are Shaded in Green

Sample	Elapsed Time (min)	Cumulative Time (min)	Cumulative Time (sec)	Square Root of Time (sec)	Tan-Gr 0002-01	Amt. Abs. 0002-01	Mi 0002-01
Dry Weight	0	0	0	0.00	26.36	0.00	0.00
4/19/02 8:05	5	5	300	17.32	27.25	0.89	0.08
4/19/02 8:12	7	12	720	26.83	27.44	1.08	0.10
4/19/02 8:19	7	19	1,140	33.76	27.47	1.11	0.10
4/19/02 8:25	6	25	1,500	38.73	27.73	1.37	0.12
4/19/02 8:32	7	32	1,920	43.82	27.74	1.38	0.12
4/19/02 8:38	6	38	2,280	47.75	27.77	1.41	0.12
4/19/02 8:48	10	48	2,880	53.67	27.76	1.40	0.12
4/19/02 8:58	10	58	3,480	58.99	27.82	1.46	0.13
4/19/02 9:08	10	68	4,080	63.87	27.80	1.44	0.13
4/19/02 9:23	15	83	4,980	70.57	27.82	1.46	0.13
4/19/02 9:38	15	98	5,880	76.68	27.81	1.45	0.13
4/19/02 9:53	15	113	6,780	82.34	27.82	1.46	0.13
4/19/02 10:11	18	131	7,860	88.66	27.85	1.49	0.13
4/19/02 10:41	30	161	9,660	98.29	27.85	1.49	0.13
4/19/02 11:11	30	191	11,460	107.05	27.89	1.53	0.14
4/19/02 12:11	60	251	15,060	122.72	27.92	1.56	0.14
4/19/02 13:11	60	311	18,660	136.60	27.97	1.61	0.14
4/19/02 14:11	60	371	22,260	149.20	27.96	1.60	0.14
4/19/02 20:11	360	731	43,860	209.43	28.13	1.77	0.16
4/20/02 8:11	720	1,451	87,060	295.06	28.24	1.88	0.17
4/20/02 20:11	720	2,171	130,260	360.92	28.32	1.96	0.17
4/21/02 8:00	709	2,880	172,800	415.69	28.36	2.00	0.18
4/21/02 21:00	720	3,600	216,000	464.76	28.36	2.00	0.18
4/22/02 8:00	720	4,320	259,200	509.12	28.33	1.97	0.17
4/22/02 20:00	720	5,040	302,400	549.91	28.40	2.04	0.18
4/23/02 20:00	1,440	6,480	388,800	623.54	28.51	2.15	0.19
4/24/02 20:00	1,440	7,920	475,200	689.35	28.54	2.18	0.19
4/25/02 20:00	1,440	9,360	561,600	749.40	28.52	2.16	0.19
4/27/02 8:00	2,160	11,520	691,200	831.38	28.52	2.16	0.19
% Moisture Gained in Capillary Absorption					8.19%	CpAbsCoeff	0.0028
Fully Saturated					28.52		
Imbibation Capacity %					8.19%		
Mp, Vp					2.16		
Diff between Cap Abs and Total Imm.					0.00%		
Water Level					170.00		
With Sample					182.00		
Water Displaced (ml)					12.00		
Vp/Va*100=% Porosity					18.00%		

Table 18 - Brick Capillary Absorption

Example Raw Data, Calculated Values are Shaded in Green

Color	R-O	R-O	R-T	R-T	R-O	T
Type	River	River	Lake	Lake	River	Lake
Sample	0009-04	0009-04x	0013-01x	0013-01	0045-02	0089-03
Depth (cm)	1.90	2.10	1.80	1.70	1.80	1.90
Width(cm)	3.30	2.80	3.50	3.70	3.50	3.40
Height(cm)	3.60	3.60	3.60	3.60	3.60	3.60
Surface Area (cm^2)	6.27	5.88	6.30	6.29	6.30	6.46
Volume (cm^3)	22.57	21.17	22.68	22.64	22.68	23.26
Density (g/$cm^{3)}$	1.68	1.66	1.69	2.00	1.56	1.67
4/19/02 11:37	37.87	35.22	38.39	45.26	35.28	38.80
4/19/02 11:42	41.44	41.75	44.18	47.70	40.19	43.64
4/19/02 11:47	41.64	41.82	44.25	47.79	40.67	44.34
4/19/02 11:52	41.74	41.84	44.25	47.84	40.84	44.42
4/19/02 11:57	41.83	41.85	44.28	47.88	40.93	44.45
4/19/02 12:02	41.91	41.87	44.29	47.91	40.99	44.46
4/19/02 12:07	41.99	41.87	44.28	47.92	41.01	44.47
4/19/02 12:17	42.09	41.87	44.27	47.97	41.07	44.49
4/19/02 12:27	42.21	41.90	44.31	48.02	41.10	44.51
4/19/02 12:37	42.29	41.89	44.28	48.04	41.09	44.51
4/19/02 12:52	42.43	41.92	44.32	48.09	41.13	44.53
4/19/02 13:07	42.53	41.93	44.32	48.12	41.14	44.53
4/19/02 13:22	42.61	41.91	44.30	48.14	41.14	44.54
4/19/02 13:37	42.71	41.94	44.32	48.17	41.16	44.56
4/19/02 14:07	42.84	41.95	44.35	48.24	41.19	44.59
4/19/02 14:37	42.96	41.97	44.32	48.27	41.19	44.61
4/19/02 15:37	43.05	41.99	44.32	48.35	41.22	44.61
4/19/02 16:37	43.07	42.04	44.32	48.41	41.26	44.66
4/19/02 17:37	43.09	42.08	44.35	48.47	41.29	44.70
4/19/02 22:37	43.19	42.28	44.43	48.64	41.40	44.85
4/20/02 11:37	43.36	42.60	44.59	48.98	41.66	45.25
4/20/02 23:05	43.46	42.78	44.78	49.26	41.87	45.42
4/21/02 11:37	43.57	42.96	44.91	49.44	42.00	45.56
4/21/02 23:05	43.66	43.11	45.05	49.58	42.13	45.66
4/22/02 11:00	43.66	43.16	45.09	49.66	42.23	45.73
4/22/02 23:00	43.77	43.26	45.17	49.73	42.32	45.81
4/23/02 23:00	43.87	43.37	45.26	49.77	42.40	45.91
4/24/02 22:30	43.96	43.45	45.35	49.84	42.46	45.97
4/25/02 20:30	44.05	43.56	45.47	49.91	42.59	46.11
4/27/02 8:30	44.13	43.61	45.54	49.92	42.65	46.17
% Moisture Gained in Cap. Abs.	16.53%	23.82%	18.62%	10.30%	20.89%	18.99%
Fully Saturated	44.34	43.85	45.78	50.16	42.96	46.33
% Moisture Gained in Total Imm.	17.08%	24.50%	19.25%	10.83%	21.77%	19.41%
Mp, Vp	6.47	8.63	7.39	4.90	7.68	7.53
Diff betw. Cap Abs and Total Imm.	0.55%	0.68%	0.63%	0.53%	0.88%	0.41%
Water Level	170.00	170.00	170.00	170.00	170.00	170.00
With Sample	196.00	198.00	199.00	200.00	191.00	190.00
Va Water Displaced (ml)	26.00	28.00	29.00	30.00	21.00	20.00
Vp/Va*100=% Porosity	24.88%	30.82%	25.48%	16.33%	36.57%	37.65%

Table 19 - Stucco Drying Curve and Drying Rate Data
Example Raw Data - Calculated Values are Shaded in Green

			0009-07, Gray Layer									
Drying Curve	Cum. Time (hrs)	Change in Time Hours Δt	Wt of Sample (W_T)	Water Content (U_T g)	Relative Moisture Content (Y)	Residual Water Content (Q%)	Moisture Content (Ψ)	Relative Moisture Content Diff. (ΔY)	Relative Moisture Lost ($\Delta Y/\Delta t$)	Diff. in Moisture Content $\Delta(\psi)$	Diff in Moisture Content ($\Delta\Psi/\Delta t$)	Relative Moisture Content (Y%)
4/30/02 9 00	0 00	0.00	31 37	2.23	1 00	7.65%	0.038	0.00	0.00	0.00	0.00	100.00%
4/30/02 9 07	0.12	0.12	31 28	2.14	0.96	7.34%	0 037	0 040	0.346	0 002	0.0132	95 96%
4/30/02 9 13	0.22	0.10	31 25	2.11	0.95	7 24%	0 036	0 013	0 135	0 001	0 0051	94 62%
4/30/02 9 20	0 33	0.12	31 25	2.11	0.95	7.24%	0.036	0.000	0 000	0 000	0 0000	94 62%
4/30/02 9 29	0 48	0.15	31 25	2.11	0.95	7 24%	0 036	0.000	0 000	0.000	0 0000	94 62%
4/30/02 9 39	0 65	0.17	31 22	2 08	0.93	7.14%	0 036	0.013	0 081	0 001	0 0031	93 27%
4/30/02 9 49	0 82	0.17	31 18	2.04	0.91	7.00%	0.035	0.018	0.108	0.001	0.0041	91 48%
4/30/02 9 59	0.98	0.17	31 12	1.98	0.89	6.79%	0.034	0.027	0.161	0.001	0.0062	88 79%
4/30/02 10 15	1.25	0.27	31 05	1.91	0.86	6.55%	0 033	0.031	0.118	0.001	0 0045	85.65%
4/30/02 10 30	1 50	0.25	30 99	1.85	0.83	6.35%	0 032	0 027	0 108	0.001	0 0041	82 96%
4/30/02 10 45	1.75	0.25	30 95	1.81	0.81	6.21%	0 031	0.018	0 072	0.001	0 0027	81.17%
4/30/02 11 00	2.00	0.25	30.89	1 75	0.78	6.01%	0.030	0.027	0.108	0.001	0.0041	78 48%
4/30/02 11 30	2.50	0.50	30 79	1.65	0.74	5.66%	0.028	0.045	0.090	0.002	0.0034	73.99%
4/30/02 12 00	3 00	0.50	30 73	1.59	0.71	5.46%	0.027	0.027	0.054	0.001	0.0021	71.30%
4/30/02 13 00	4 00	1.00	30.58	1 44	0.65	4.94%	0.025	0.067	0.067	0.003	0.0026	64 57%
4/30/02 14 00	5.00	1.00	30 52	1.38	0.62	4.74%	0.024	0.027	0 027	0.001	0 0010	61.88%
4/30/02 15 00	6.00	1.00	30 46	1.32	0.59	4.53%	0.023	0.027	0.027	0.001	0.0010	59.19%
4/30/02 16 00	7.00	1.00	30 43	1 29	0.58	4.43%	0 022	0 013	0.013	0.001	0.0005	57 85%
4/30/02 17 00	8 00	1.00	30 38	1.24	0.56	4 26%	0.021	0.022	0 022	0 001	0.0009	55.61%
4/30/02 18 00	9.00	1.00	30 36	1.22	0.55	4 19%	0.021	0.009	0.009	0.000	0.0003	54 71%
4/30/02 20 00	11 00	2.00	30 32	1 18	0.53	4.05%	0.020	0 018	0.009	0.001	0 0003	52.91%
4/30/02 23 00	14 00	3.00	30 28	1 14	0.51	3.91%	0.019	0.018	0.006	0.001	0.0002	51.12%
5/1/02 8 00	23 00	9 00	30.20	1.06	0.48	3.64%	0.018	0.036	0.004	0.001	0.0002	47.53%
5/1/02 23 00	38.00	15.00	30.06	0.92	0.41	3.16%	0 016	0.063	0.004	0.002	0.0002	41.26%
5/2/02 8 00	47 00	9 00	30 01	0.87	0.39	2.99%	0.015	0.022	0.002	0 001	0.0001	39.01%
Full Dry Weight W_d			29 14					Critical moisture content Ψ_c			0 034	g/cm^3
Total Water Content Recalculat			7 65%					Critical moisture content Y_c			88 79%	%

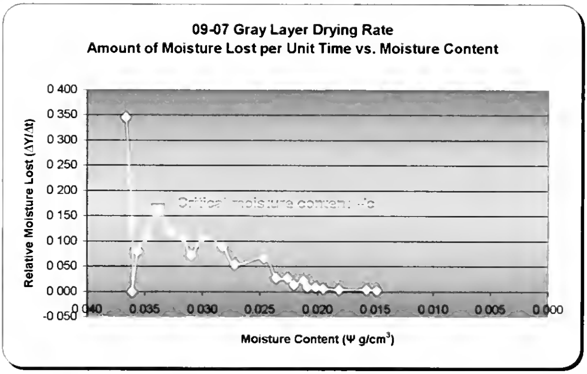


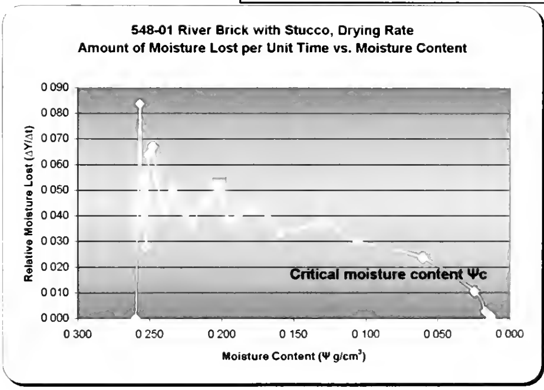
Table 20 - Brick Drying Curve and Drying Rate Data
Example Raw Data - Calculated Values are Shaded in Green

0548-01, with Stucco, Lake Brick

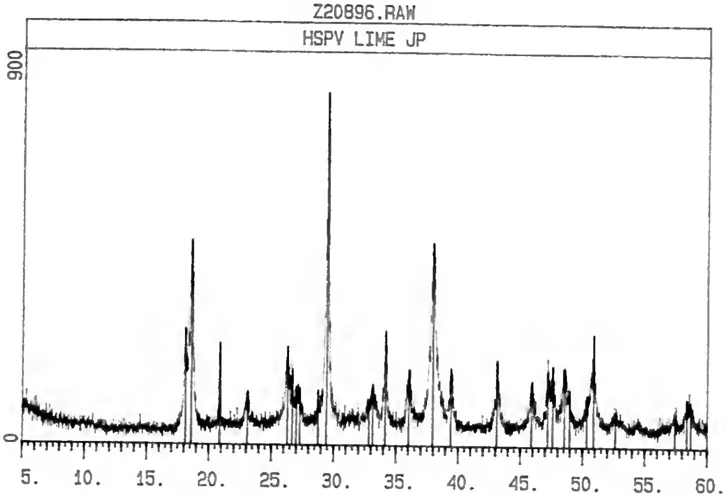
Drying Curve	Cum. Time (hrs)	Change in Time Hours Δt	Wt. of Sample (W_T)	Water Content (U_T g)	Relative Moisture Content (Y)	Residual Water Content (Q%)	Moisture Content (Ψ)	Relative Moisture Content Diff. (ΔY)	Relative Moisture Lost (ΔY/Δt)	Diff. in Moisture Content Δ(ψ)	Diff in Moisture Content (ΔΨ/Δt)	Relative Moisture Content (Y%)
5/2/02 9 30	0 00	0 00	38.32	5.37	1.00	16.30%	0 260	0.000	0 000	0.000	0 000	100 00%
5/2/02 9 38	0.13	0 13	38.26	5.31	0.99	16 12%	0 257	0.011	0 084	0 003	0 022	98 88%
5/2/02 9 43	0 22	0 08	38 24	5.29	0.99	16 05%	0 256	0 004	0 045	0 001	0.012	98.51%
5/2/02 9 49	0.32	0 10	38 22	5.27	0.98	15 99%	0 255	0.004	0 037	0 001	0.010	98.14%
5/2/02 9 55	0 42	0 10	38 19	5.24	0.98	15 90%	0 253	0.006	0 056	0 001	0 015	97 58%
5/2/02 10 03	0.55	0.13	38 17	5.22	0.97	15 84%	0 253	0 004	0.028	0 001	0 007	97.21%
5/2/02 10 10	0 67	0 12	38 13	5 18	0.96	15 72%	0 251	0 007	0 064	0.002	0 017	96 46%
5/2/02 10 20	0.83	0 17	38 07	5.12	0 95	15.54%	0 248	0.011	0 067	0 003	0 017	95 34%
5/2/02 10 30	1 00	0 17	38 02	5.07	0 94	15.39%	0 245	0.009	0.056	0.002	0 015	94 41%
5/2/02 10 45	1.25	0.25	37 96	5.01	0.93	15.20%	0 242	0.011	0.045	0 003	0 012	93 30%
5/2/02 11 06	1 60	0 35	37 88	4.93	0 92	14 96%	0 238	0 015	0 043	0.004	0.011	91.81%
5/2/02 11 26	1.93	0.33	37 79	4.84	0.90	14 69%	0 234	0.017	0.050	0 004	0 013	90 13%
5/2/02 11 46	2 27	0.33	37 71	4.76	0 89	14 45%	0.230	0.015	0.045	0 004	0 012	88 64%
5/2/02 12 16	2.77	0 50	37 60	4 65	0 87	14 11%	0 225	0 020	0.041	0 005	0 011	86 59%
5/2/02 12 46	3 27	0.50	37 50	4.55	0.85	13 81%	0 220	0 019	0 037	0 005	0 010	84 73%
5/2/02 13 16	3.77	0 50	37 38	4.43	0.82	13 44%	0.214	0.022	0 045	0 006	0 012	82.50%
5/2/02 13 45	4 25	0 48	37 26	4.31	0.80	13.08%	0.208	0.022	0 046	0.006	0 012	80 26%
5/2/02 14 15	4.75	0.50	37 12	4.17	0.78	12 66%	0 202	0 026	0 052	0 007	0 014	77 65%
5/2/02 14 50	5 33	0 58	37 00	4 05	0.75	12 29%	0.196	0 022	0 038	0 006	0.010	75 42%
5/2/02 15 30	6 00	0 67	36 86	3 91	0 73	11.87%	0.189	0.026	0 039	0.007	0 010	72 81%
5/2/02 16 30	7.00	1 00	36 63	3 68	0.69	11.17%	0.178	0.043	0 043	0 011	0 011	68 53%
5/2/02 17 30	8 00	1.00	36 42	3 47	0 65	10 53%	0 168	0.039	0 039	0 010	0 010	64 62%
5/2/02 18 30	9 00	1.00	36.24	3 29	0 61	9 98%	0 159	0 034	0 034	0 009	0 009	61 27%
5/2/02 21 30	12.00	3.00	35 64	2.69	0 50	8 16%	0 130	0 112	0 037	0.029	0 010	50.09%
5/3/02 0 30	15 00	3 00	35 15	2.20	0.41	6 68%	0 106	0 091	0 030	0 024	0 008	40.97%
5/3/02 8 00	22.50	7.50	34 20	1 25	0 23	3 79%	0 060	0.177	0 024	0 046	0 006	23 28%
5/3/02 21 00	35 50	13 00	33 46	0 51	0.09	1 55%	0 025	0 138	0 011	0 036	0 003	9 50%
5/4/02 8 00	46.50	11.00	33 30	0.35	0 07	1.06%	0 017	0 030	0 003	0 008	0 001	6.52%
5/4/02 22 00	60.50	14 00	33 23	0 28	0 05	0 85%	0.014	0 013	0 001	0 003	0.000	5.21%
5/5/02 8 00	70.50	10.00	33 23	0.28	0 05	0.85%	0 014	0 000	0.000	0 000	0.000	5.21%

Critical moisture content Ψ_c	0 202	g/cm^3
Critical moisture content Y_c	77 65%	%

Full Dry Weight Wd 32 95



XRD Scans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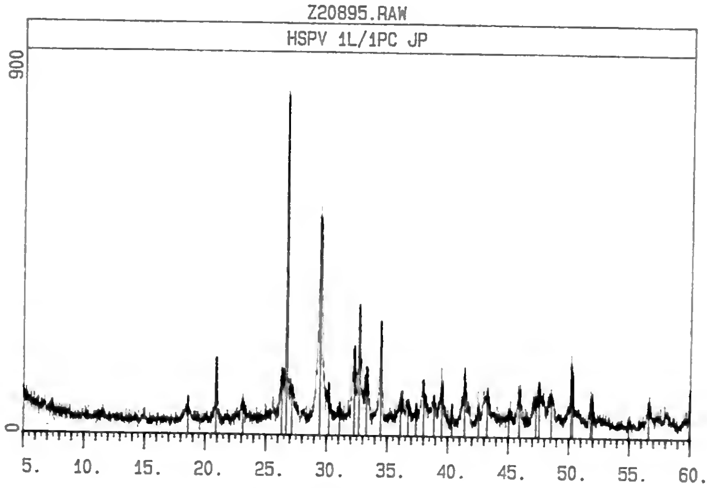
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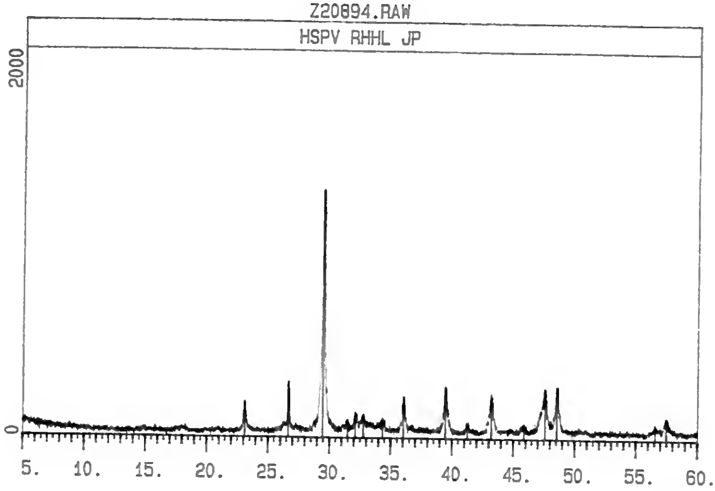
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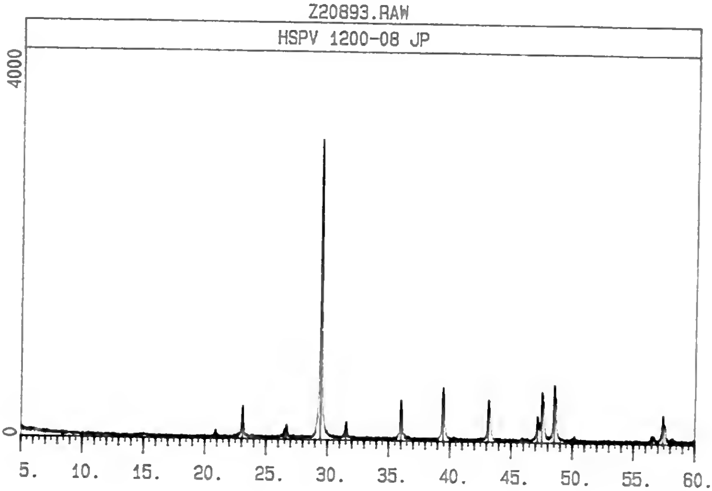
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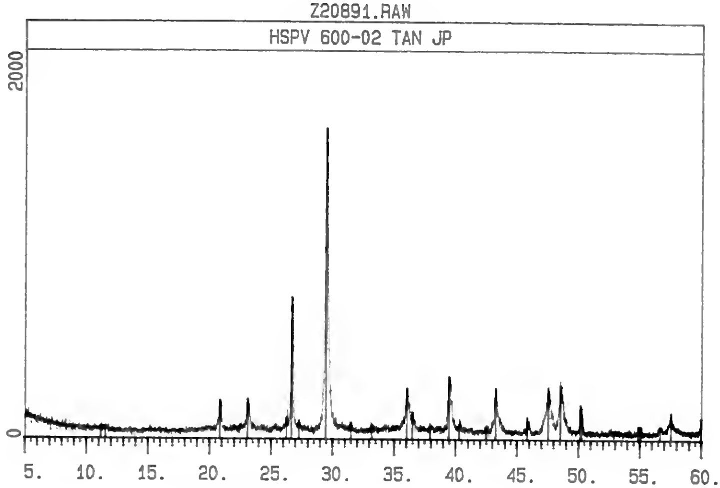
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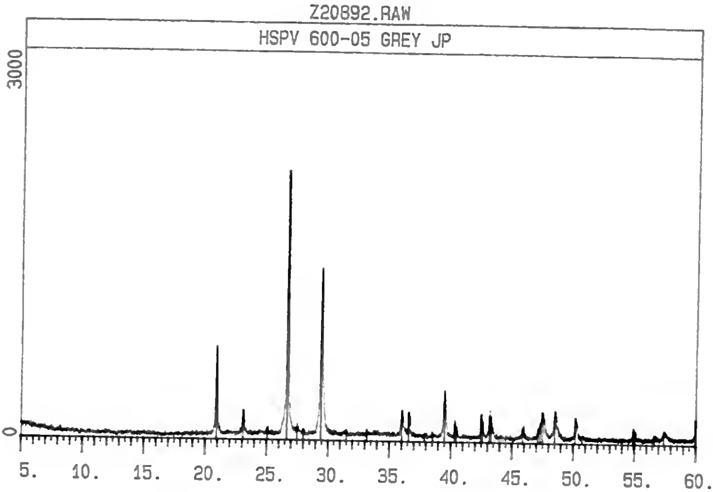
55.
60.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55.
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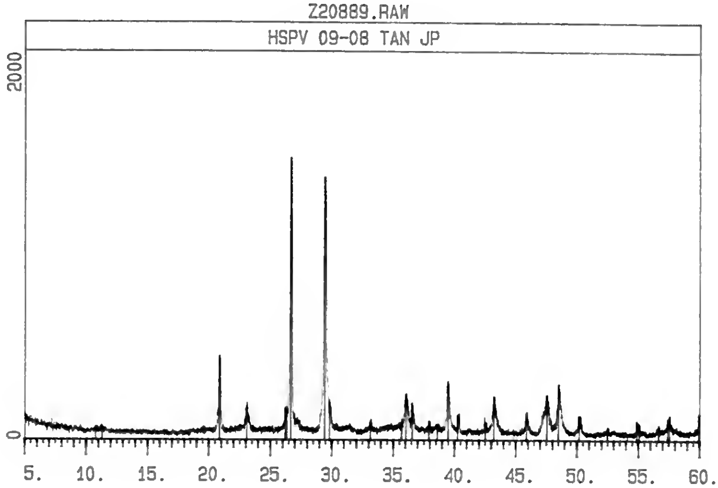
XRD Scans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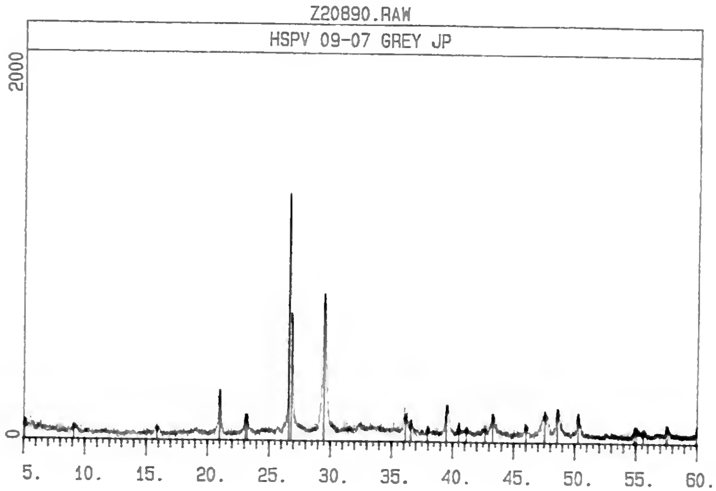
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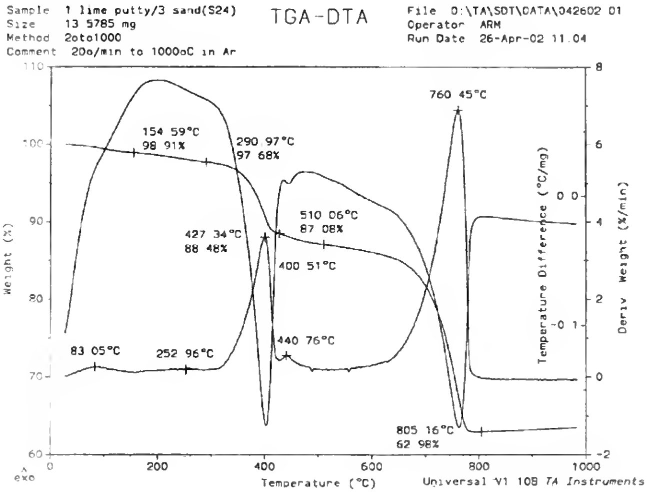

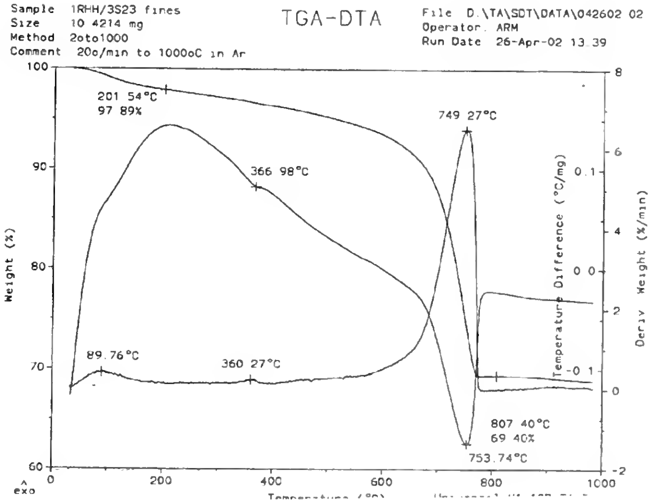

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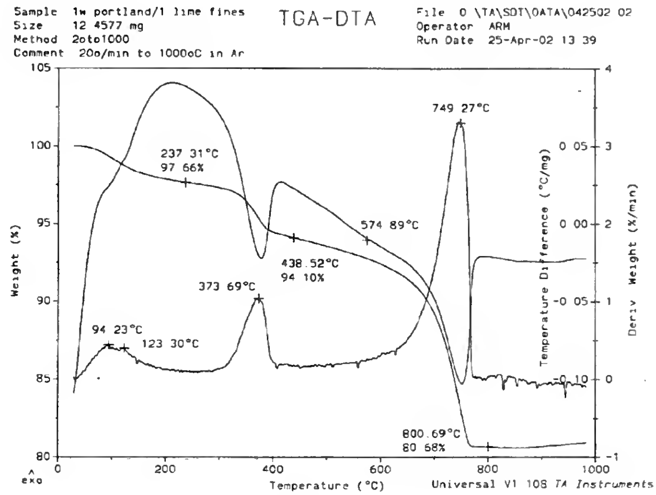

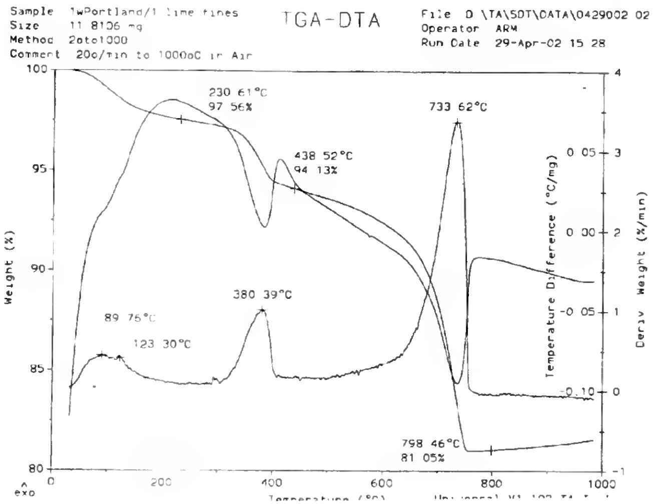

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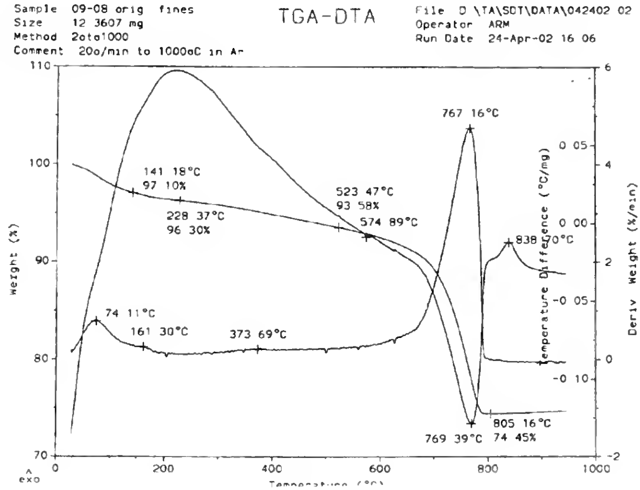

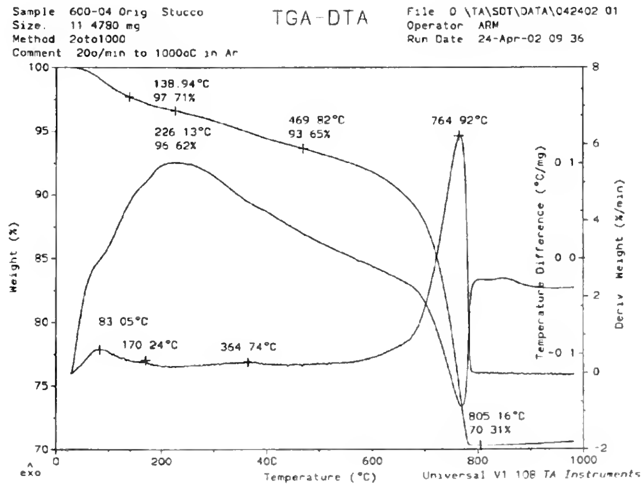

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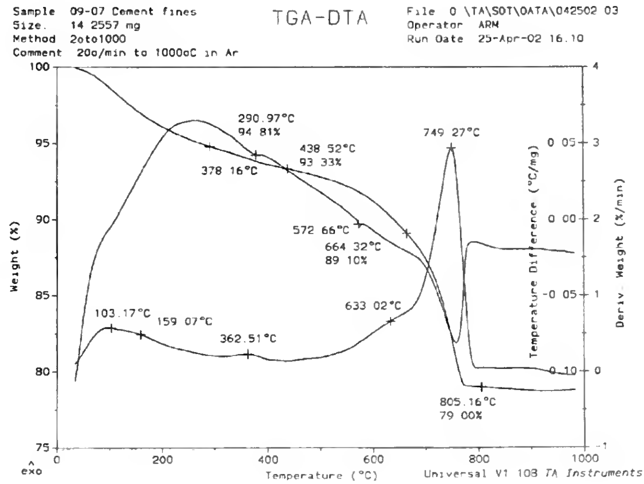

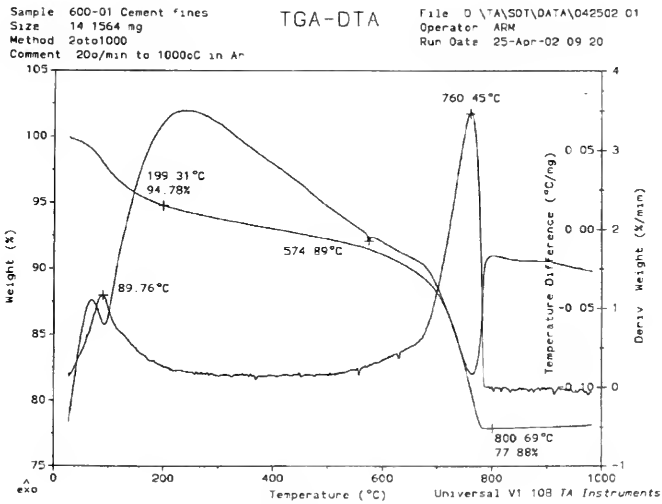

Appendix D

Summary Results

Table 21 – Summary Moisture Response Data for All Groups

Category	No.	Density g/cm^3	WVT (g/day*m^2)	Cap. Absorp Coeff. g/cm^2 sec$^{0.5}$	Imbibition Capacity %	Est. % Open Porosity	Critical Moisture Content	Critical Moisture Content %
Bricks								
All Brick	31	1.70	468.72	0.0352	18.81%	30.50%	0.1436	45.43%
Imported (Bare)	1	1.95						
All Lake Brick	16	1.73	436.44	0.0312	16.91%	28.25%	0.1721	57.51%
All River Brick	14	1.66	519.61	0.0418	21.67%	33.95%	0.1160	32.12%
Bare Lake	6	1.70	601.52	0.0341	18.18%	28.68%	0.1532	48.51%
Lake w/ Stucco	10	1.75	326.39	0.0294	16.15%	28.00%	0.1835	62.91%
Bare River	6	1.60	711.61	0.0471	23.93%	36.22%	0.0313	7.60%
River w/Stucco	8	1.70	375.60	0.0378	19.97%	32.25%	0.1795	50.51%
Stucco								
All Stucco	35	0.44	116.70	0.0023	11.52	19.90%	0.0311	61.93%
White xSF	3	0.42	123.08	0.0052	23.02	34.18%	0.0215	33.68%
Tan xSF	7	0.45	174.66	0.0025	12.21	21.29%	0.0309	53.86%
DkTan xSF	5	0.43	136.61	0.0024	11.73	19.62%	0.0272	51.72%
Gray xSF	5	0.45	80.37	0.0019	9.04	15.23%	0.0364	82.57%
WhiteGray xSF	3	0.41	115.26	0.0023	11.05	21.79%	0.0380	80.06%
Combinations xSF	5	0.44	99.20	0.0016	9.93	17.52%	0.0298	64.96%
Original Stucco xSF	15	0.43	145.76	0.0028	14.06	23.02%	0.0292	50.58%
New & Combos xSF	13	0.44	95.66	0.0019	9.85	17.63%	0.0342	75.22%
Mortar	22				25.36			

Table 22 - Tomb Combinations, All Key Data

Samples Tested	1st Date Visible	WVT (g/day*m2)	Initial M_{SAT}	% Imbibition Capacity	Capillary Absorption %	Initial Slope Total Imm.	% Open Porosity	Density g/cm^3	g/cm^2 sec$^{0.5}$ Csp. Absorp. Coeff.	Critical Moisture Content Ψ_c (g/cm^3)	Critical Moisture Content Y_c%	% Fines	% Acid Soluble	% Coarse	Fines+ AcidSol/ Course
02-01 Tan-Gr w/SF	1921	36 18		8 19	8 19		18	0 45	0 0028	0 027	56 25%				
02-02 Tan xSF			13 08			0 0263	28 3								
02-05 WhGray xSF		170 3	12 24	13.19	13 1	0.025	26.28	0 37	0 0042	0 029	52 59%				
02-03 Mortar			13 89			0 275	13 8					16 56	19 51	63 94	0 56
No Brick															
09-08 Tan xSF	1822		10 65	10 65		0.012	18 00					9 73%	30 92%	59 35%	0 68
09-04 Tan-Gr xSF		32 44		8 49	8 07		15 57	0 45	0 0015	0 028	71 25%				
09-07 Gray xSF		36 26		6 25	6 21	0 019	11 50	0 50	0 0012	0 034	88 79%	15.45%	22 90%	61 65%	
09-03 Mortar			11.36			0 525	20 90					9 76%	22 09%	68 15%	0 47
09-04 RB w/Stucco		475 29		17 08	16 53		24 88	1.68	0 0329	0 122	41.75%				
09-04 RB xStucco		772 35	23 27	24 50	23 82		30 82	1 66	0 0641	0 009	2.14%				
13-02 Tan wSF	1830		11 24			0 0104	23 8					14 12	32.28	53 6	0 87
13-03 Mortar			14 16			0 275	18.3					7 27	19 35	73 38	0 36
13-01 LB w/Stucco		176 19		10 83	10 3		16 33	1 99	0 0184	0 106	45 37				
13-01 LB xStucco		742 86	17 43	19 25	18 62		24 48	1 69	0.0430	0 068	19 85				
39-03 Tan xSF	No Date	198 79		8 86	8 62	0.01	16 64	0 47	0 0026	0 027	56 04%	16 61%	32 56%	50 84%	0 97
39-04 Gray xSF		130 15		13 66	13 66	0 02	21 36	0 42	0 0046	0 054	84 83%	10 32%	33 77%	55 91%	0 79
No Mortar															
No Brick															
45-01 Tan xSF	1834	165 48		15 36	15 11	0 0236	25 58	0 42	0 0032	0 035	52 98%	12 11	46.7	41 19	1 43
45-03 Mortar			30 67			1 025	48					39 29	26 78	33 92	0 02
45-02 RB wStucco		390 96		21 77	20 89		36 57	1 55	0 0368	0 188	53.65				
			22.53												
89-02 DkTan w/SF	1922	136 37		8 66	8 46	0 010	18 21	0 53	0 0020	0 04	78 93%				
89-02 DkTan xSF		133 86		11 56	11 56	0 014	19 86	0 43	0 0016	0 031	57 32%	11 24%	33 71%	55 06%	0 82
89-05 Mortar			17 52			0 500	32.90					19 33%	11 25%	69 42%	0 44
89-03 LB w/Stucco		340 66		19 41	18 99		37 65	1 67	0 0365	0 219	66 10%				
89-03 LB x/Stucco			18 16												
89-04 RB w/Stucco		402 93		20 05	19 68		37 65	1.76	0 0430	0 193	53 08%				
89-04 RB xStucco		754 78	22 66	24 36	23 81		39 26	1 53	0 0448	0 015	3 96%				
No Stucco on Tomb 92	1919														
92-01 Mortar			32 22			1 25	45 00					38 97%	38 34%	22 69%	0 03
92-02 ImpB xStucco		240 48	10 09	9 11	8 63		18 04	1 95	0 0077	0 073	38 43%				

Tomb Combinations, 1 of 3

Table 22 - Tomb Combinations, All Key Data

Samples Tested	1st Date Visible	WVT (g/day*m2)	Initial M_{SAT}	% Imbibition Capacity	Capillary Absorption %	Initial Slope Total Imm.	% Open Porosity	Density g/cm³	g/cm² sec^0.5 Cap. Absorp. Coeff.	Critical Moisture Content Ψ_c (g/cm³)	Critical Moisture Content Y_c%	% Fines	% Acid Soluble	% Coarse	Fines+ AcidSol / Course
107-03 DkTan xSF	1867		9 02			0 010	13 80					12 32%	36 40%	51 28%	0 95
107-02 Mortar			22 04			1 18	37 10					20 12%	10.18%	69 70%	0 43
107-01 RB wStucco		397 62		19 69	19 17			1 64	0 0339	0 037	11 13%				
107-01 RB xStucco			24 91												
120-02 DkTan-Gr	1812	95 52		8 91	8 74		14.75		0 0015	0.038	85 57%				
120-03 Mortar			32 14			1 38	47 70					50.24%	20 92%	28 84%	0 02
120-01 LB wStucco		166 67		15 11	14 87		22 96	1 75	0 0304	0.215	77 11%				
120-01 LB xStucco		616 67	16 34	18 07	17 52		30 05	1 70	0 0366	0 218	68 52%				
146-03 Tan-Gr xStucco	1835	164 34		9 98	9 55	0 015	15 63	0 44	0 0012	0 022	45 51%				
146-06 Tan xStucco			8 63			0 0126	16 30								
146-05 Gray xStucco			7 69			0 018	21 30								
146-02 Mortar			34 29			1 03	47 00					41 90%	36.53%	22 56%	3 43%
146-01 LB wStucco		496 89		14 55	14 33		26 10	1 8200	0 0305	0.218	78 49%				
146-01 LB xStucco		617 56	17.01	18 12	17 70		27 87	1 6100	0 0343	0 231	76 59%				
200-03 White xSF	1822	112 02		20 82	20 40	0 027	29 80	0 36	0 0025	0 047	61.06%	15 62%	58 65%	25.74%	2 89%
200-04 DkTan xSF		153.37		11 05	11 05	0 018	16 25	0 43	0 0024	0.038	73 93%	18 42%	36 25%	45 33%	1 21%
200-01 DkTan-Gr xSF		144 76		8 61	8 42	0 009	14 59	0 47	0 0011	0 038	86 53%				
200-05 Gray xSF		40 79		8 39	8 29	0 005	14 47	0 43	0 0012	0 037	91 24%	12 66%	38 34%	49 00%	1 04%
No Mortar															
No Brick															
251-05 Tan xSF	1826		11 11			0 020	21 40								
251-02 Mortar			32 72			1.125	44 50					52 62%	24 91%	22 48%	3 45%
251-01 RB wStucco		390 79		19 34	18 94		28 37	1 65	0 0327	0 21	63 11%				
251-01 RB xStucco			24 39												
259-04 White xSF	1823	123 08		13 65	13 65	0 020	21 05	0 39	0 0022	0 032	56 48%	4 35%	54 43%	41 22%	1 43%
259-05 Mortar			18 06			0 116	31 10					10 19%	50 49%	39 32%	1 54%
259-02 RB wStucco		254 95		22.35	21 65		36 59	1 64	0 0423	0 193	52 66%				
259-02 RB xStucco			24 26												
259-01 RB wStucco		328 67		17 73	17.28		30 45	1 90	0 0359	0 253	73.25%				
259-01 RB xStucco		726 19	21 66	22 28	21 81		35 79	1 56	0 0428	0 015	4 31%				
548-02 Tan w/SF	1820	110 32		11 77	11 49	0 018	18 60	0 49	0 0018	0 04	66 84%				
548-02 Tan xSF		164 81		12 97	12 86		19 56	0 46	0 0024	0 028	45 41%	10 23%	37 27%	52 50%	90 00%
548 Mortar				24 75			38.30					40 38%	21 59%	38 04%	1 63%
548-01 LB w/Stucco		208 70		15 74	15 32		27 37	1 60	0 0277	0 202	77 65%				
548-01 LB xStucco		614 18	15 16	18 73	18 32		29 45	1 76	0 0351	0 169	49 83%				

Tomb Combinations, 2 of 3

Table 22 - Tomb Combinations, All Key Data

Samples Tested	1st Date Visible	WVT (g/day*m2)	Initial M_{SAT}	% Imbibition Capacity	Capillary Absorption %	Initial Slope Total Imm.	% Open Porosity	Density g/cm^3	g/cm^2 sec$^{0.5}$ Cap. Absorp. Coeff.	Critical Moisture Content Ψ_c (g/cm^3)	Critical Moisture Content Y_c%	% Fines	% Acid Soluble	% Coarse	Fines+ AcidSol / Course
0558-04 DkTan w/SF	No Date		9.71			0.0129	17.00					9.04	38.64	52.32	0.91
0558-05 Tan w/SF			13.99			0.0297	25.00					17.31	27.13	55.57	0.8
0558-02 Gray x/SF			9.62			0.0144	18.80					10.14	30.3	59.56	0.68
No Mortar															
558-01 LB w/Stucco				16.45	16.11		28.91	1.71	0.0224	0.231	79.33				
558-01 LB x/Stucco			19.21												
558-02 LB w/ Stucco		445.13		17.32	16.85		30.36	1.75	0.0348	0.157	50.29				
558-02 LB x/ Stucco			16.64												
558-03 RB xStucco		802.05	21.27	22.35	21.86		39.14	1.77	0.0453	0.054	13.23				
573-03 DkTan xSF	1853	110.32		11.47	11.22	0.0256	21.21	0.46	0.0027	0.033	60.34%				
573-02 Mortar			21.72			0.2647	37.5					28.07	8.44	63.49	0.58
573-01 LB wStucco		354.55		16.3	15.99		31.45	1.86	0.0301	0.206	65.28				
573-01 LB xStucco		597.4	17.56	19.86	19.45		33.45	1.6	0.0302	0.128	39.12				
579-05 Tan wSF	No Date	110.32		12.74	12.42		25.06		0.0029	0.046	86.83%				
579-05 Tan xSF		143.28		12.56	12.16	0.0299	20.92	0.49	0.0028	0.03	47.33%	10.18	27.69	62.13	0.61
579-04 Mortar			22.22			0.1872	33					11.78	21.36	66.85	0.5
579-03 RB wStucco		363.64		21.71	21.14		36.59	1.94	0.0452	0.24	55.45				
579-03 RB xStucco		642.86	21.63	24.55	23.92		35.87	1.53	0.0342	0.02	5.09				
600-05 Gray xSF	1824											19.49%	23.42%	57.09%	75.00%
600-04 Tan xSF		253.83		13.78	13.44	0.023	27.08	0.40	0.0028	0.017	30.03%	10.70%	27.40%	61.90%	62.00%
600-02 Tan-Gr xSF		58.93		10.93	10.52	0.021	21.57	0.47	0.0017	0.045	86.94				
600-03 Mortar				31.03		0.303	43.30					35.22%	30.74%	34.94%	1.94%
No Brick															
1200-08m White xSF	1813			32.39	32.05	0.058	47.31	0.23	0.0082	0.02	26.04%	6.81	82.04	11.15	7.97
1200-04m Mortar			31.63			0.182									
1200-12m Mortar			32.59			0.2672	40.9					35.31	45.19	19.5	4.13
1200-06m LB xStucco		420.45	13.76	15.02	14.63		25.76	1.82	0.0277	0.105	37.13				
1200-07e DkTan xSF	1813		10.41			0.0143	19.6								
1200-01e WGray xSF			14.76			0.0255	23.4					15.08	38.01	46.91	1.13
1200-09e Mortar												36.17	26.65	37.18	1.69
1200-11e Mortar			31.7			1.03	46.3					29.75	52.99	17.26	4.79
1200-05e RB xStucco		571.43	22.28	25.56	25.07		36.46	1.68	0.0512	0.075	16.87				

Tomb Combinations, 3 of 3

Table 23 - Summary Data for All Stucco Discs

Sample	With SF?	Color Type	Sort	Tomb Type	1st Visible Date	Dry Weight	Diameter cm	Thickness cm	Surface Area cm^2	Volume cm^3	Density g/cm^3
0002-01	SF	Tan-Gr	5	Parapet	1921	25.81	5.4	2.510	22.90	57.485	0.45
0002-05		White Gr	6	Parapet	1921	35.05	5.3	4.310	22.06	95.087	0.37
0004-01	SF	DkTan	3	Platform	1958	36.16	5.3	3.250	22.06	71.701	0.50
0009-04		Tan-Gr	5	Platform	1822	54.84	5.4	5.280	22.90	120.924	0.45
0009-07		Gray	4	Platform	1822	29.14	5.3	2.650	22.06	58.464	0.50
0039-03		Tan	2	Parapet	No Date	20.46	5.3	1.960	22.06	43.241	0.47
0039-04		Gray	4	Parapet	No Date	21.48	5.3	2.320	22.06	51.184	0.42
0044-01		Gray	4	Platform	1851	27.79	5.2	3.130	21.24	66.472	0.42
0045-01		Tan	2	Parapet	1834	31.41	5.2	3.550	21.24	75.392	0.42
0089-02	SF	Dk Tan	3	Platform	1922	29.28	5.1	2.700	20.43	55.156	0.53
0089-02x		Dk Tan	3	Platform	1922	37.44	5.2	4.130	21.24	87.710	0.43
0120-02		DkTan-Gr	5	Parapet	1812	39.95	5.2	3.980	21.24	84.524	0.47
0146-03		Tan-Gr	5	Platform	1835	29.43	5.1	3.310	20.43	67.618	0.44
0200-01		DkTan-Gr	5	Platform	1822	37.02	5.1	3.880	20.43	79.262	0.47
0200-03		White	1	Platform	1822	28.49	5.3	3.540	22.06	78.099	0.36
0200-04		DkTan	3	Platform	1822	29.09	5.2	3.190	21.24	67.747	0.43
0200-05		Gray	4	Platform	1822	29.06	5.3	3.070	22.06	67.730	0.43
0226-03		Dk Tan	3	Parapet	1806	22.17	5.2	2.750	21.24	58.402	0.38
0239-02		Tan	2	Platform	1854	39.00	5.2	4.270	21.24	90.683	0.43
0259-04		White	1	Platform	1823	28.70	5.1	3.560	20.43	72.725	0.39
0275-02		White Gr	6	Wall Vault	1851	33.52	5.3	3.030	22.06	66.848	0.50
0291-02		Dk Tan	3	Parapet	1927	39.94	5.3	4.090	22.06	90.233	0.44
0508-01	SF	Dk Tan	3	Pediment	1853	38.18	5.2	4.030	21.24	85.586	0.45
0548-02	SF	Tan	2	Parapet	1820	31.42	5.2	3.050	21.24	64.774	0.49
0548-02x		Tan	2	Parapet	1820	26.92	5.2	2.780	21.24	59.039	0.46
0550-01	SF	DkTan	3	Platform	1866	34.35	5.3	3.370	22.06	74.349	0.46
0551-01	SF	Gray	4	Parapet	No Date	28.86	5.2	2.730	21.24	57.978	0.50
0573-03		Dk Tan	3	Parapet	1853	44.06	5.2	4.550	21.24	96.629	0.46
0579-05		Tan	2	Parapet	No Date	31.23	5.2	3.630	21.24	77.091	0.41
0579-05x		Tan	2	Parapet	No Date	19.86	5.2	1.920	21.24	40.775	0.49
0581-01		Gray	4	Platform	No Date	15.88	5.2	1.530	21.24	32.493	0.49
0600-02		Tan	2	Pediment	1824	41.04	5.3	4.050	22.06	89.351	0.46
0600-04		Tan-Gr	5	Pediment	1824	23.33	5.3	2.670	22.06	58.905	0.40
0602-02		White Gr	6	Pediment	No Date	28.97	5.3	3.620	22.06	79.864	0.36
1200-08		White	1	Wall Vault	1813	23.02	Broke	4.780			

Stucco Discs Summary, 1 of 3

Table 23 - Summary Data for All Stucco Discs

Sample	With SF?	Color Type	WVT (g/day*m^2)	Cap Abs Coefficient	Imbibition Capacity	Est. % Porosity	Critical Moisture Content	Critical Moisture Content
0002-01	SF	Tan-Gr	36.18	0.0028	8.19	18.00%	0.027	56.25%
0002-05		White Gr	170.30	0.0042	13.19	26.28%	0.029	52.59%
0004-01	SF	DkTan	119.15	0.0014	8.18	18.63%	0.028	61.33%
0009-04		Tan-Gr	32.44	0.0015	8.49	15.57%	0.025	63.33%
0009-07		Gray	36.26	0.0012	6.25	11.50%	0.034	88.79%
0039-03		Tan	198.79	0.0026	8.86	16.64%	0.027	56.04%
0039-04		Gray	130.15	0.0046	13.66	21.36%	0.038	59.75%
0044-01		Gray	32.96	0.0013	9.11	14.94%	0.036	88.06%
0045-01		Tan	165.48	0.0032	15.36	25.58%	0.035	52.98%
0089-02	SF	Dk Tan	136.37	0.0020	8.66	18.21%	0.032	62.50%
0089-02x		Dk Tan	133.86	0.0016	11.56	19.86%	0.025	47.13%
0120-02		DkTan-Gr	95.52	0.0015	8.81	14.75%	0.026	57.98%
0146-03		Tan-Gr	164.34	0.0012	9.98	15.63%	0.022	45.51%
0200-01		DkTan-Gr	144.76	0.0011	8.61	14.59%	0.031	71.06%
0200-03		White	40.79	0.0025	20.82	29.80%	0.043	55.78%
0200-04		DkTan	112.02	0.0027	11.05	16.25%	0.024	46.99%
0200-05		Gray	153.37	0.0012	8.39	14.47%	0.037	91.24%
0226-03		Dk Tan	203.82	0.0019	14.83	23.71%	0.025	41.71%
0239-02		Tan	121.75	0.0016	12.05	19.71%	0.033	58.38%
0259-04		White	123.08	0.0022	13.65	21.05%	0.023	41.32%
0275-02		White Gr	31.08	0.0013	6.89	11.65%	0.038	94.03%
0291-02		Dk Tan	123.03	0.0030	9.72	17.04%	0.029	62.44%
0508-01	SF	Dk Tan	160.77	0.0031	11.78	18.88%	0.030	53.31%
0548-02	SF	Tan	110.32	0.0018	11.77	18.60%	0.040	68.84%
0548-02x		Tan	164.81	0.0024	12.97	19.56%	0.028	45.41%
0550-01	SF	DkTan	126.27	0.0018	9.20	16.74%	0.023	50.76%
0551-01	SF	Gray	23.54	0.0008	6.29	13.07%	0.027	77.83%
0573-03		Dk Tan	110.32	0.0027	11.47	21.21%	0.033	60.34%
0579-05		Tan	143.28	0.0029	12.74	25.06%	0.046	86.83%
0579-05x		Tan	Out	0.0028	12.56	20.92%	0.030	47.33%
0581-01		Gray	49.11	0.0012	7.80	13.89%	0.037	85.00%
0600-02		Tan	253.83	0.0017	10.93	21.57%	0.017	30.03%
0600-04		Tan-Gr	58.93	0.0028	13.78	27.08%	0.045	86.94%
0602-02		White Gr	144.40	0.0014	13.08	27.43%	0.047	93.56%
1200-08		White	Out	0.0082	32.39	47.31%	0.020	26.04%

Stucco Discs Summary, 2 of 3

Table 23 - Summary Data for All Stucco Discs

Sample	With SF?	Color Type	% Fines	% Acid Soluble	% Agg.	S1	S2	S3	S4	S5	S6	S7
0002-01	SF	Tan-Gr										
0002-05		White Gr										
0004-01	SF	DkTan										
0009-04		Tan-Gr										
0009-07		Gray	15.45%	22.90%	61.65%	0.15%	0.35%	4.02%	63.39%	24.65%	6.50%	0.94%
0039-03		Tan										
0039-04		Gray										
0044-01		Gray	11.98%	25.91%	62.11%	0.23%	3.27%	8.47%	60.05%	21.14%	4.85%	1.99%
0045-01		Tan	12.11%	46.70%	41.19%	0.06%	3.90%	26.63%	30.41%	27.61%	10.05%	1.34%
0089-02	SF	Dk Tan	11.24%	33.71%	55.06%	0.04%	0.56%	18.65%	66.25%	10.30%	3.12%	1.08%
0089-02x		Dk Tan										
0120-02		DkTan-Gr										
0146-03		Tan-Gr										
0200-01		DkTan-Gr										
0200-03		White	15.62%	58.65%	25.74%	4.87%	12.87%	18.25%	36.51%	15.05%	6.84%	5.60%
0200-04		DkTan	18.42%	36.25%	45.33%	0.69%	7.71%	18.28%	50.69%	17.29%	4.15%	1.19%
0200-05		Gray	12.66%	38.34%	49.00%	0.00%	2.92%	10.12%	53.75%	26.96%	4.82%	1.42%
0226-03		Dk Tan										
0239-02		Tan										
0259-04		White	4.35%	54.43%	41.22%	0.12%	0.27%	2.08%	77.33%	16.53%	3.04%	0.65%
0275-02		White Gr										
0291-02		Dk Tan										
0508-01	SF	Dk Tan										
0548-02	SF	Tan	10.23%	37.27%	52.50%	0.04%	0.26%	13.63%	74.68%	8.56%	2.12%	0.71%
0548-02x		Tan										
0550-01	SF	DkTan										
0551-01	SF	Gray										
0573-03		Dk Tan	10.18%	27.69%	62.13%	0.04%	0.14%	12.72%	68.08%	14.82%	3.64%	0.56%
0579-05		Tan										
0579-05x		Tan										
0581-01		Gray	19.41%	22.54%	58.05%	0.89%	5.21%	12.49%	63.41%	13.15%	3.95%	0.89%
0600-02		Tan	19.49%	23.42%	57.09%	0.17%	6.94%	12.19%	39.63%	28.87%	7.37%	4.83%
0600-04		Tan-Gr										
0602-02		White Gr										
1200-08		White	7.50%	86.92%	5.58%	3.03%	2.02%	8.08%	41.92%	33.33%	10.10%	1.52%

Stucco Discs Summary, 3 of 3

Table 24 - Summary Data for All Brick Cubes

Sample	With Stucco?	Type	Color Type	1st Visible Date	Dry Weight	Depth (cm)	Width (cm)	Height (cm)	Surface Area cm^2	Volume cm^3	Density g/cm^3	Weight Change (g)
0092-01x	Bare	Imported	RR	1919	45.43	1.80	3.70	3.50	6.66	23.31	1.95	0.0010
0013-01x	Bare	Lake	R-T	1830	38.34	1.80	3.50	3.60	6.30	22.68	1.69	0.0031
0120-01x	Bare	Lake	T-O	1812	36.43	1.70	3.50	3.60	5.95	21.42	1.70	0.0026
0146-01x	Bare	Lake	R-T	1835	35.27	1.90	3.50	3.30	6.65	21.95	1.61	0.0026
0548-01x	Bare	Lake	R-T	1820	31.41	1.80	3.20	3.10	5.76	17.86	1.76	0.0026
0573-01x	Bare	Lake	T-O	1853	33.60	2.00	3.50	3.00	7.00	21.00	1.60	0.0025
1200-06x	Bare	Lake	T	1813	49.53	2.30	3.70	3.20	8.51	27.23	1.82	0.0018
0013-01	Yes	Lake	R-T	1830	45.03	1.70	3.70	3.60	6.29	22.64	1.99	0.0007
0089-03	Yes	Lake	T	1922	38.71	1.90	3.40	3.60	6.46	23.26	1.66	0.0014
0120-01	Yes	Lake	T-O	1812	40.85	1.80	3.70	3.50	6.66	23.31	1.75	0.0007
0146-01	Yes	Lake	R-T	1835	35.74	1.80	3.20	3.40	5.76	19.58	1.82	0.0021
0334-01	Yes	Lake	R-T	1838	38.33	1.80	3.50	3.70	6.30	23.31	1.64	0.0012
0548-01	Yes	Lake	R-T	1820	32.95	1.90	3.20	3.40	6.08	20.67	1.59	0.0009
0558-01	Yes	Lake	R-T	No Date	38.56	1.90	3.30	3.60	6.27	22.57	1.71	Out
0558-02	Yes	Lake	T-O	No Date	38.51	1.80	3.30	3.70	5.94	21.98	1.75	0.0019
0573-01	Yes	Lake	T-O	1853	38.49	1.80	3.70	3.10	6.66	20.65	1.86	0.0015
0593-02	Yes	Lake	T	No Date	40.33	1.90	3.60	3.40	6.84	23.26	1.73	0.0019
0009-04x	Bare	River	R-O	1822	35.02	2.10	2.80	3.60	5.88	21.17	1.65	0.0032
0089-04x	Bare	River	R	1922	30.56	1.90	3.00	3.50	5.70	19.95	1.53	0.0031
0259-01x	Bare	River	R	1823	38.50	1.90	3.60	3.60	6.84	24.62	1.56	0.0030
0558-03x	Bare	River	R-O	No Date	36.70	1.90	3.30	3.60	6.27	22.57	1.63	0.0033
0579-03x	Bare	River	R-O	No Date	33.45	1.90	4.10	2.80	7.79	21.81	1.53	0.0027
1200-05x	Bare	River	R-O	1813	36.82	1.90	3.30	3.50	6.27	21.95	1.68	0.0024
0009-04	Yes	River	R-O	1822	37.73	1.90	3.30	3.60	6.27	22.57	1.67	0.0020
0045-02	Yes	River	R-O	1834	35.12	1.80	3.50	3.60	6.30	22.68	1.55	0.0016
0089-04	Yes	River	R	1922	37.54	1.80	3.30	3.60	5.94	21.38	1.76	0.0017
0107-01	Yes	River	R-O	1867	38.16	1.90	3.50	3.50	6.65	23.28	1.64	0.0017
0251-01	Yes	River	R-O	1826	39.44	1.90	3.60	3.50	6.84	23.94	1.65	0.0016
0259-01	Yes	River	R	1823	37.67	1.70	3.50	3.50	5.95	20.83	1.81	0.0014
0259-02	Yes	River	R-O	1823	36.07	1.70	3.50	3.70	5.95	22.02	1.64	0.0011
0579-03	Yes	River	R-O	No Date	36.92	1.60	3.60	3.40	5.76	19.58	1.89	0.0015

Brick Cubes Summary, 1 of 2

Table 24 - Summary Data for All Brick Cubes

Sample	WVT ($g/day*m^2$)	Cap Abs Coefficient	Imbibition Capacity	Est. % Porosity	Critical Moisture Content	Critical Moisture Content
0092-01x	240.48	0.0077	9.11%	18.04%	0.073	38.43%
0013-01x	742.86	0.0408	19.25%	25.48%	0.068	19.85%
0120-01x	616.67	0.0366	18.07%	30.05%	0.218	68.52%
0146-01x	617.56	0.0343	18.12%	27.87%	0.231	76.59%
0548-01x	614.18	0.0351	18.73%	29.45%	0.169	49.83%
0573-01x	597.40	0.0302	19.86%	33.45%	0.128	39.12%
1200-06x	420.45	0.0277	15.02%	25.76%	0.105	37.13%
0013-01	176.19	0.0261	10.83%	16.33%	0.106	45.37%
0089-03	340.66	0.0365	19.41%	37.65%	0.219	66.10%
0120-01	166.67	0.0304	15.11%	22.96%	0.215	77.11%
0146-01	496.89	0.0305	14.55%	26.10%	0.218	78.49%
0334-01	296.31	0.0330	17.24%	28.83%	0.133	44.62%
0548-01	208.70	0.0277	15.74%	27.37%	0.202	77.65%
0558-01	Out	0.0224	16.45%	28.91%	0.231	79.33%
0558-02	445.13	0.0348	17.32%	30.36%	0.157	50.29%
0573-01	354.55	0.0301	16.30%	31.45%	0.206	65.28%
0593-02	452.38	0.0228	18.57%	30.04%	0.148	44.86%
0009-04x	772.35	0.0641	24.50%	30.82%	0.009	2.14%
0089-04x	754.78	0.0448	24.36%	39.26%	0.015	3.96%
0259-01x	726.19	0.0428	22.28%	35.79%	0.015	4.31%
0558-03x	802.05	0.0453	22.35%	39.14%	0.054	13.23%
0579-03x	642.86	0.0342	24.55%	35.87%	0.02	5.09%
1200-05x	571.43	0.0512	25.56%	36.46%	0.075	16.87%
0009-04	475.29	0.0329	17.08%	24.88%	0.122	41.75%
0045-02	390.96	0.0368	21.77%	36.57%	0.188	53.65%
0089-04	402.93	0.0430	20.05%	34.36%	0.193	53.08%
0107-01	397.62	0.0339	19.69%	30.20%	0.037	11.13%
0251-01	390.79	0.0327	19.34%	28.37%	0.21	63.11%
0259-01	328.67	0.0359	17.73%	30.45%	0.253	73.25%
0259-02	254.95	0.0423	22.35%	36.59%	0.193	52.66%
0579-03	363.64	0.0452	21.71%	36.59%	0.24	55.45%

Brick Cubes Summary, 2 of 2

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